G.E.C. Journal

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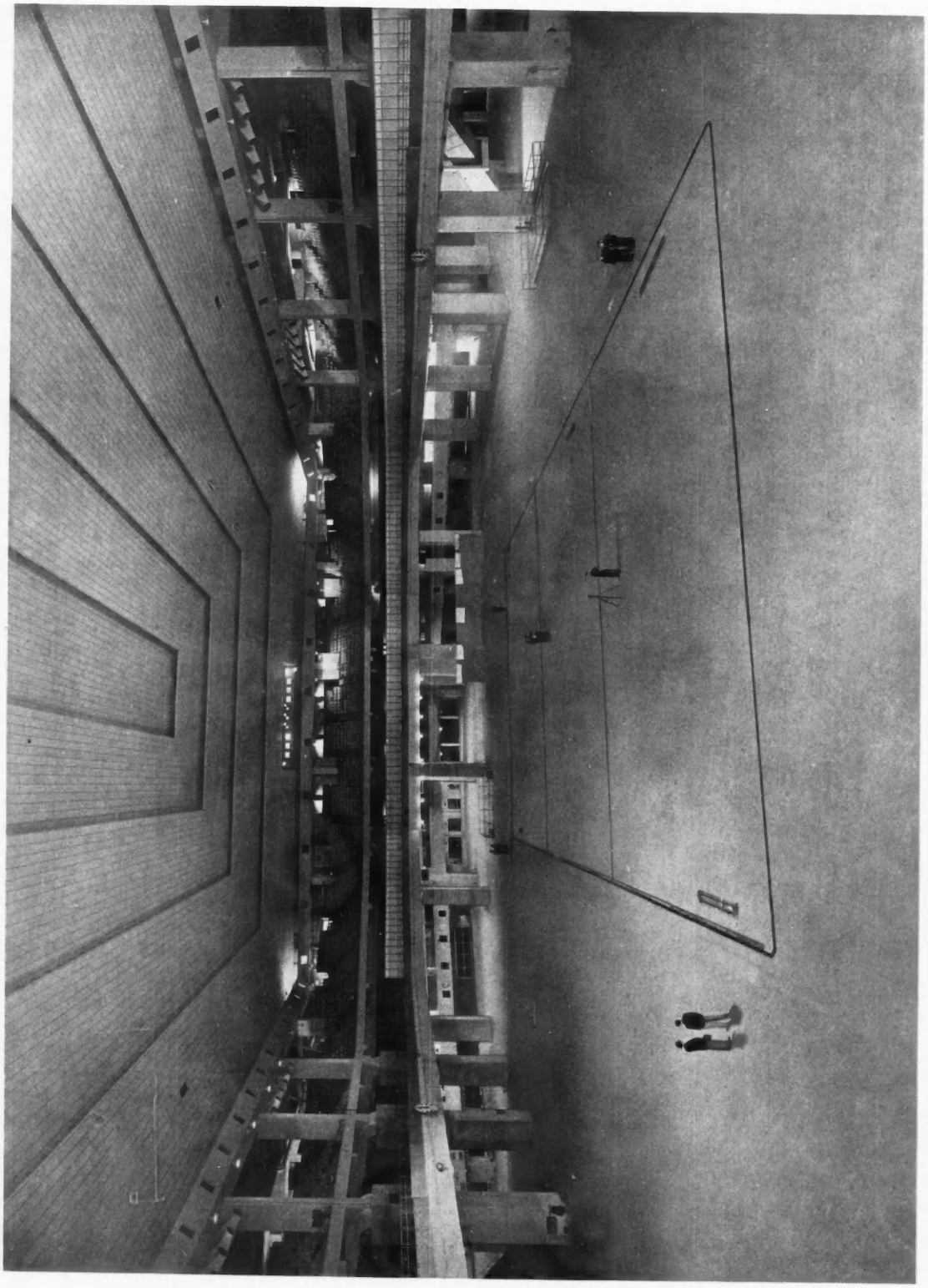


720-TON ADJUSTABLE FLOOR AT EARLS COURT.
The Central Exhibition Hall of the Earls Court Exhibition, London, showing the adjustable floor of the swimming pool raised to the surrounding floor level.

G.E.C. Journal

VOL. VIII. NOVEMBER, 1937. No. 4.

Earls Court Swimming Pool.

THE DESIGN AND CONSTRUCTION OF A 720-TON ADJUSTABLE FLOOR.

By W. J. HUGGETT, M.I.Mech.E., A.M.I.E.E.

Fraser & Chalmers' Engineering Works of The General Electric Co., Ltd.

THE new Earls Court Exhibition building which has just been completed is one of the foremost accomplishments of modern constructional engineering; moreover it is the largest reinforced concrete building in England and covers an area of 13 acres.

The central exhibition hall has a roof span of 250 feet and a height of approximately 115 feet. In the centre of this hall is situated what is perhaps the most prominent feature of the Earls Court undertaking, namely a swimming pool which contains an adjustable floor of 720 tons weight. The pool is the largest indoor swimming pool in England, measuring 195 feet long by 95 feet broad.

When the scheme was first considered it was realized that the pool would not be required for swimming purposes throughout the whole of the year; therefore a means had to be found for covering the pool over, thus rendering it an integral part of the hall floor, and making the whole of the hall area available for exhibitions, various forms of entertainment, etc. This problem was referred to the Fraser & Chalmers Engineering Works of The General Electric Co., Ltd., and eventually a scheme was prepared involving the use of an adjustable floor in the pool itself, covering its whole area. It was established that this floor could be designed to fulfil certain further functions, and the contract which was finally placed required a floor which had to be capable of satisfying the following essential conditions:—

1. To form part of the main floor when the

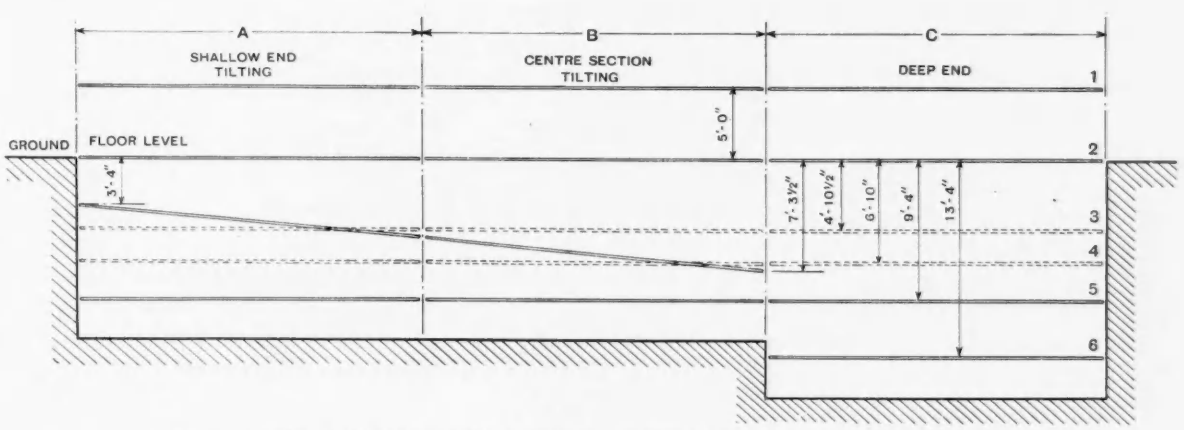


Fig. 1.—Sectional diagram of the swimming pool, showing the positions in which the moving platforms can be arranged.

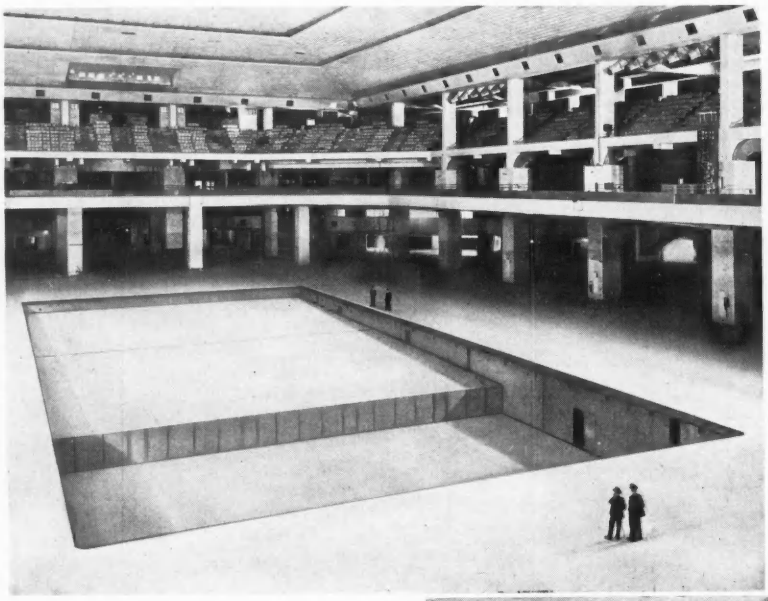


Fig. 2.—The moving platforms arranged to provide a shallow end and a deep end for diving.

space was required for exhibition purposes, and to be capable of carrying in this position a "live" load of 6 cwts. per sq. ft.

2. To permit of tilting so that the floor of the pool would slope from the shallow end to the deep end; and also when required give an extra depth of water at the deep end for high diving.

3. To provide a sunken arena by sinking the whole floor or part of the floor to various levels, below the main floor level.

4. To serve as a raised stage or platform over all or part of its area above the main floor level.

To meet these conditions the floor is divided into three equal sections each 65 ft. long × 95 ft. wide. Each section is entirely separate from the others and is operated independently, and the sections of the floor can be moved and permanently supported in the following positions:

1. All three sections level with the main floor.

2. One end section and the centre section lowered and tilted at a depth sloping from 3ft. 4in. to 7ft. 3½in.

3. The remaining end section lowered to a maximum diving depth of 13ft. 4in.

4. All three sections set at various independent levels below the main floor varying from 4ft. 10½in. to 9ft. 4in.

5. All three sections raised independently to a height of 5ft. above the exhibition floor.

A diagram indicating the various positions which may be obtained is shown in the accompanying fig. 1, while the photographs reproduced at figs. 2, 3 and 4 show the floor when installed in some of these positions. To raise and lower the sections (each of which weighs 240 tons unloaded) direct acting hydraulic pressure is used.

The floor is designed to carry 200 lbs. per sq. ft. which is sufficient for ordinary exhibition purposes, but for heavy machinery exhibitions, 600 lbs. per sq. ft. loading had to be arranged for. Temporary supports are provided to meet this condition, the system adopted being described later.

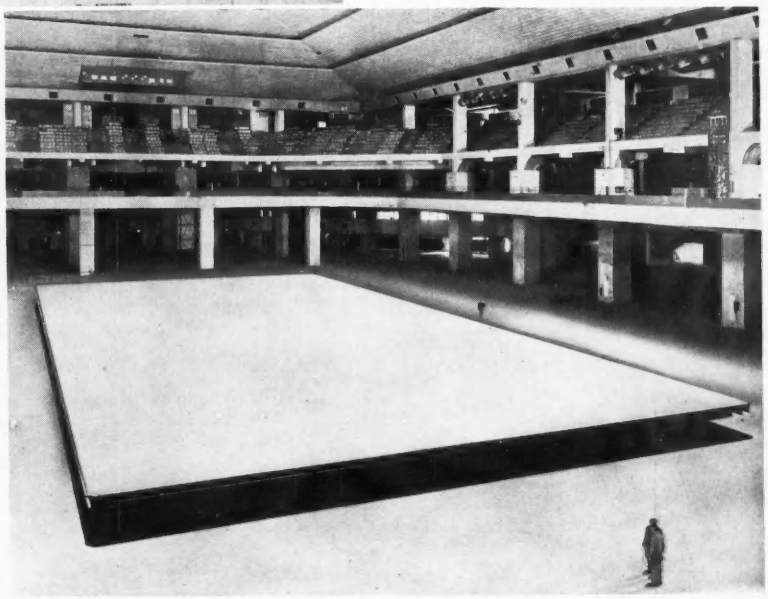


Fig. 3.—The three platforms raised 5 ft. above floor level to form an elevated stage.

In the detailed description of the construction of the floor which follows, frequent reference is made to fig. 7 and reference letters throughout the text will be found upon this illustration.

FLOOR SECTIONS.

Each section of the floor consists of two parts—(1) the understructure of main supporting plate girders with their bracing, and (2) a super-structure of rigid steel joists and floor plates. The under-

structure consists of a heavy steel plate girder main under-frame fully braced and rigid, which is shown in course of construction in fig. 4. From this structure is carried the super-structure consisting of $\frac{1}{4}$ inch thick floor plates which are rivetted to 16 inch rigid steel joists 65 ft. long with a 3 foot spacing from centre to centre. Rivetted at right angles to the underside of these joists are four similar joists spaced at 7ft. and 28ft. from each side of the centre line. On the top of the floor plates is welded a steel mesh fabric Q to form a key for the Granolithic.

The Granolithic which forms the finished floor is $1\frac{1}{4}$ inches thick and when in position at the ground floor has the same appearance as the rest of the Exhibition floor. In the case of the two tilting sections of the floor one end of the super-structure rests on a series of bearings forming a hinge.

MAIN LIFTING RAMS AND CYLINDERS.

Two rams, A fig. 6, each 28 inches in diameter are employed for the purpose of raising or lowering each section as a whole to the required levels. These rams operate in hydraulic cylinders of special design, one of which is shown being lowered into position in fig. 5. The main hydraulic cylinders are situated in reinforced concrete pits, the flange of the cylinder which rests on the foundations in the bottom of the pool forming the watertight joint. Semi-steel ramheads having spherical bearings are securely bolted to the under-structure of each section and transmit the weight of the section to the tops of the two rams.

MAIN SUPPORTING COLUMNS OR STILTS.

The rams are used solely to lower or raise the sections, and permanent supports are provided which carry the weight of the platform and its loading in any required position. They take the form of four large stilts or columns B, attached to the underside of each section, and descend into pits formed in the bottom of the pool.

Each stilt is a steel column composite section consisting of three rolled steel joists the webs of two

Fig. 5.—One of the 28-inch hydraulic rams being lowered into position.

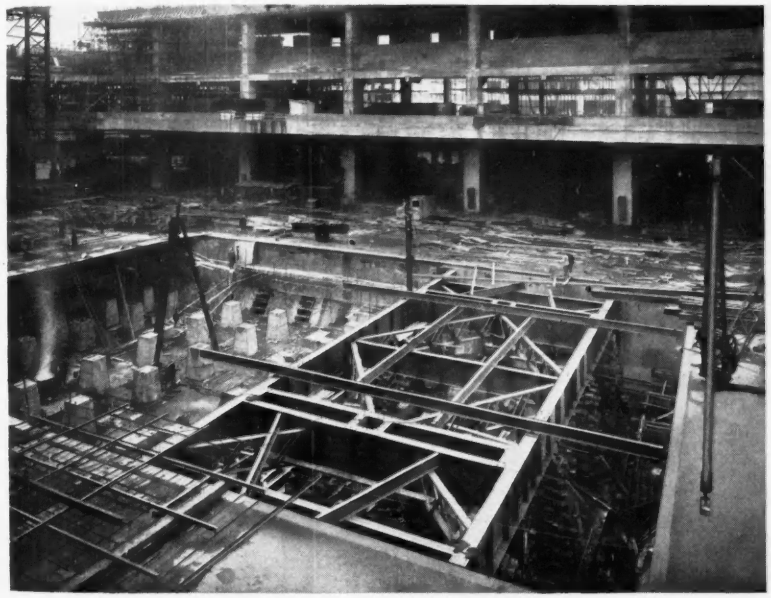


Fig. 4.—A view of the pool during construction.

of which are welded to the flanges of the centre one. On two opposite faces of each stilt are arranged cast steel brackets fixed at heights corresponding to the various levels required, and situated at the bottom of the pool are pairs of "chocks" for each stilt carried by bearings fixed to the pool floor, as shown at B. These "chocks" are geared together and operated by hydraulic rams H, and can be thrown out of action D^1 or brought into action D to engage with any set of brackets on the stilts, thus transferring the load from the rams to the "chocks" and hence to the reinforced concrete distributing beams in the bottom of the pool; thus under these conditions the hydraulic power can be turned off the main lifting rams. These four columns or stilts are

capable of supporting the whole weight of the section together with the superficial loading on the whole area of 2 cwts. per sq. ft.

Since only two rams are used to raise or lower each section, means were devised to ensure that the section would not tilt in the direction of its width during movement. To meet this problem each stilt is faced on one side with a heavy cast steel rack S. These racks are in mesh with pinions fixed at the bottom of the pool and are keyed in pairs to horizontal shafts F, thus connecting the pairs of stilts parallel with the sides of the pool. It will therefore be appreciated that any tendency for the section to tilt over its width is prevented by these racks, pinions and shafts, any unequal loading being taken up by this gear, and the sections rise and descend perfectly horizontally in this direction.

GUIDES AND GUIDE ROLLERS.

To counteract any tendency for horizontal movement in any direction each section is fitted with four sets of roller guides R attached to the under-structure of each section. These roller guides run in channel ways set into the concrete walls in the sides of the pool, two rollers operating against the flanges of the channel and one roller, at right angles, operating in the channel.

TILTING APPARATUS.

The purpose of the main rams is to raise or lower each section as a whole in a vertical direction only. The tilting of each of two sections of the platform to obtain the gradual deepening from the shallow end is performed by eight independent secondary hydraulic rams and cylinders R fixed to the main understructure of the platform. Tilting is accomplished by raising the free super-structure of each section at one end above the under-structure which always remains horizontal and rests on the "chocks." The eight hydraulic cylinders are fixed to the main girder of the understructure and the rams act on the main beam under the floor joists of the super-structure. As pressure is applied to the rams this end of the super-structure is lifted until it reaches its maximum height. At the other end the platform hinges about the bearings under each joist. As the platform rises it carries with it the upper ends of eight knee braces or toggle joints T, the other ends being attached to the lower flange of the main girder. Each brace consists of solid drawn steel tube with a knuckle joint in the centre. As the platform rises, the toggle joint straightens out and a lever and counterweight attached to the upper portion forces the toggle joint over the "dead centre" until it rests against a stop on the web of the plate girder. The super-structure is then lowered slightly until the whole weight is taken on the toggle joint which bears hard against this stop. The super-structure is now mechanically supported by these braces and the pressure on the tilting rams can be released. To lower the super-structure to the horizontal position, pressure is applied to the eight tilting rams and the super-structure rises a few inches until the toggles are nearly straight. Eight releasing rams carried from the main girder are then operated and push the knees of each brace to break the toggle, when the super-structure can be lowered to rest again on the under-structure. The hydraulic walking pipes K which feed the tilting cylinders are hinged to allow for the vertical movement of the section.

SCREEN AND GAP EDGING PLATES.

When the deep end is at its lowest position for high diving and the other two sections are tilted, as shown on fig. 2, a rubberized canvas screen G is fitted to close the vertical gap between the sections. This is fixed to the edge of the centre section and rises and falls with it.

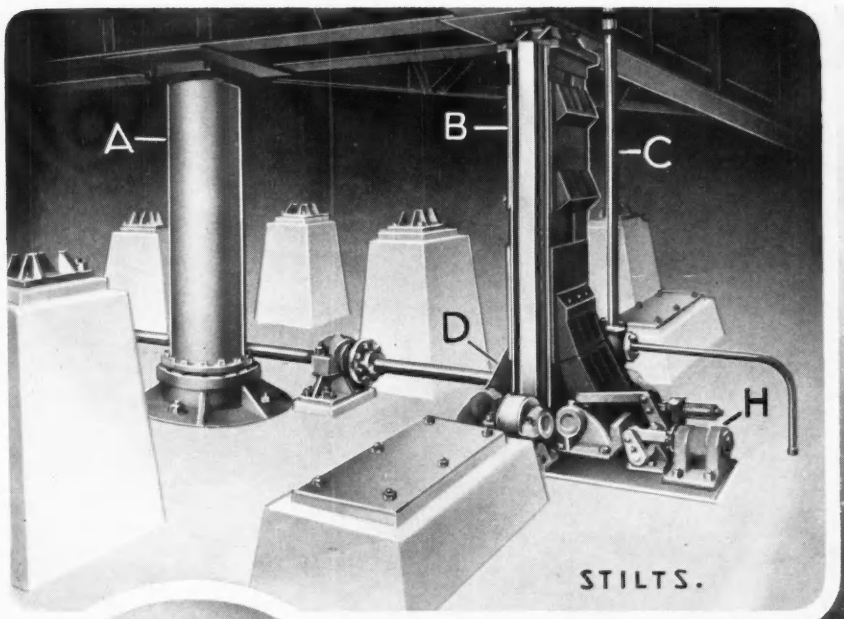
It will be understood readily that with a pool and equipment of this size a working clearance had to be arranged between the sides of the pool and the edges of the sections forming the platform, both at floor level and at all positions in the pool; edging plates are therefore arranged for both these conditions. The edging plates L are used when the sections are below Exhibition floor level to form the swimming pool.

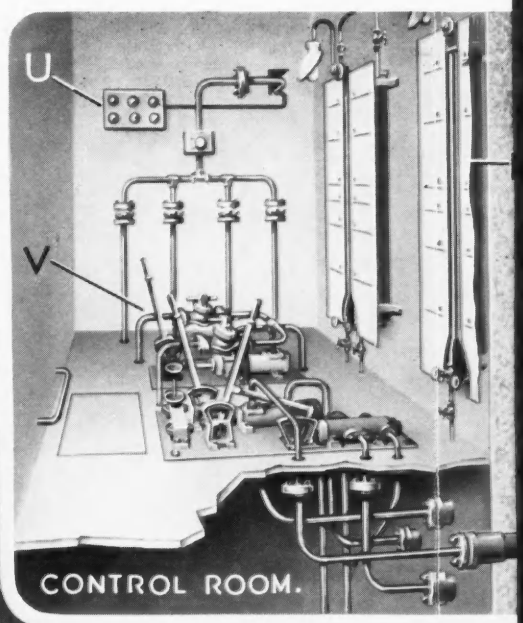
ARRANGEMENTS FOR HEAVIER LOADING.

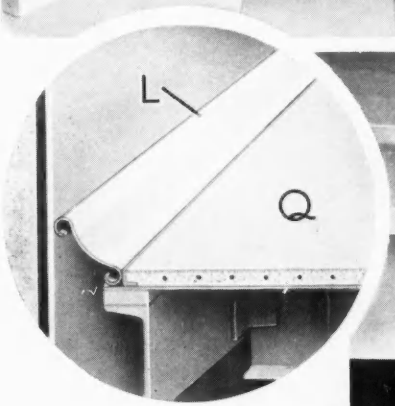
It has already been stated that the main stilts are capable of supporting the weight of the platform, together with a superficial loading of 2 cwt. per sq. ft. For the heavier loading of 6 cwt. per sq. ft. temporary stilts M and M^1 are provided. When not in use they are stored in carriers at the bottom of the pool as shown at M^1. When the heavier load has to be arranged for at the Exhibition floor level, each section is raised above this level, the temporary stilts placed in position on the concrete piers and the section then lowered to Exhibition floor level. The super-structure rests on the temporary stilts, the under-structure being carried by the system of main stilts and "chocks." The whole load is then taken by the main and temporary stilts, the total load on the whole platform being 5,550 tons.

CONTROL ROOM AND VALVES.

The whole of the platform in all its movements is completely governed from a control room situated at the side of the pool. A general view of the control room is shown in fig. 6. The control valves V are of special design, of the piston-equilibrium type and lever operated. The valves operating the







A. MAIN LIFTING RAMS.
B. STILTS.
C. INDICATOR RAM.
D. STILT CHOCKS.
D'. CHOCKS, OUT POSITION.
E. PLATFORM LIFTING RAMS.
F. SYNCHRONISING SHAFT.
G. PROTECTION APRON.
H. CHOCK OPERATING RAMS.
K. WALKING PIPES.

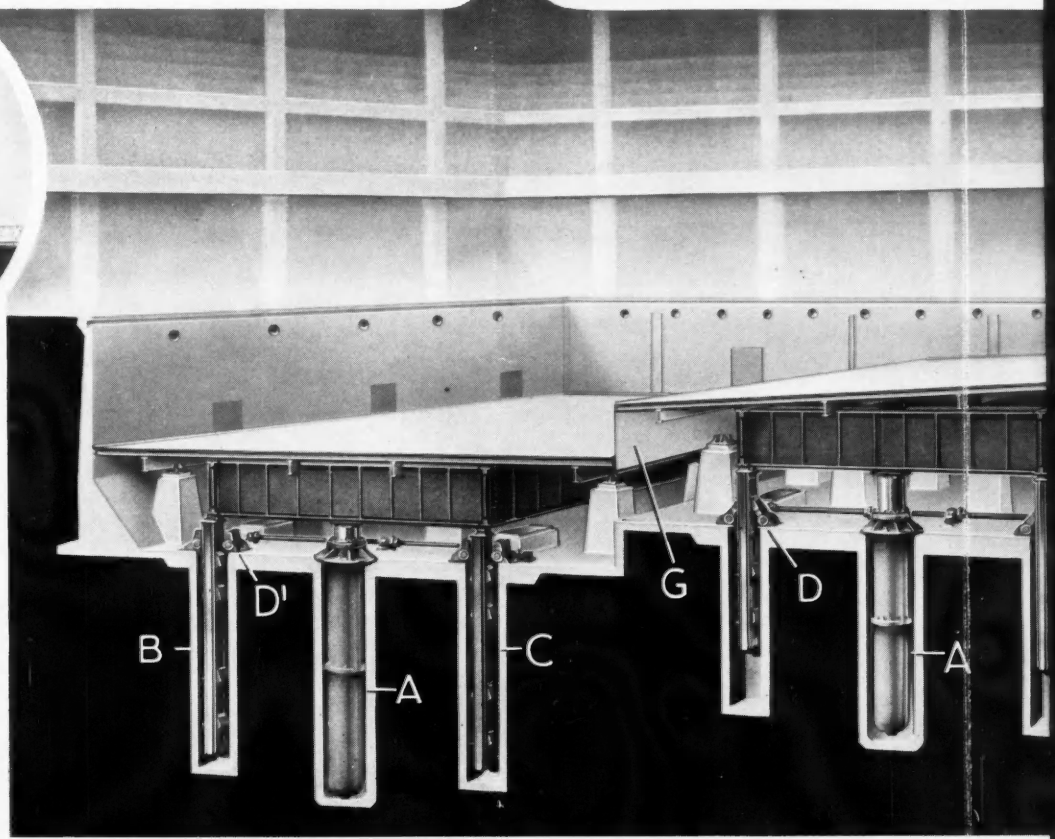
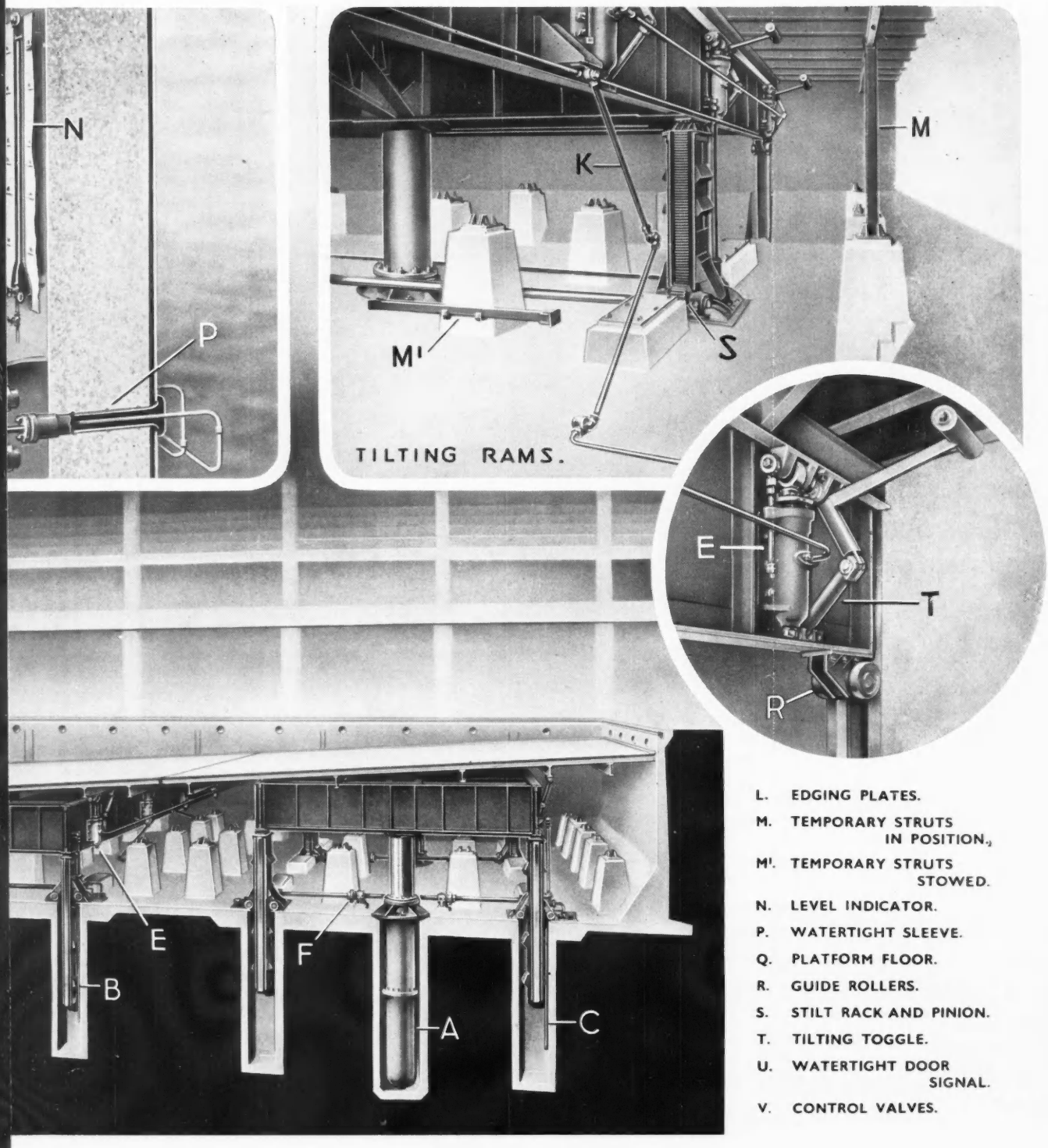


Fig. 6.—Diagrammatic illustrations of the adjustable floor in the swimming pool at E adjustable platforms each 95 ft. by 65 ft. operated by six 28-inch hydraulic rams. T shows the pool arranged for swimming with two of the platforms partly raised



L. EDGING PLATES.
M. TEMPORARY STRUTS IN POSITION.
M'. TEMPORARY STRUTS STOWED.
N. LEVEL INDICATOR.
P. WATERTIGHT SLEEVE.
Q. PLATFORM FLOOR.
R. GUIDE ROLLERS.
S. STILT RACK AND PINION.
T. TILTING TOGGLE.
U. WATERTIGHT DOOR SIGNAL.
V. CONTROL VALVES.

ol at Earls Court Exhibition. The pool measures 195 ft. by 95 ft. and has three ns. The total weight of the floor is 720 tons. The lower centre illustration raised and tilted and the third lowered to give sufficient depth for diving.

tilting gear are mechanically interlocked in such a manner that only one sequence of operation can be obtained.

Pipes from the control room to the operating gear in the pool are carried through cast iron sleeves P with packed glands on the control room side. The space around the pipes and inside the cast iron sleeve on the pool side is filled with bitumen to prevent the accumulation of still water.

Fig. 7.—"Express-S.M.S." passenger lifts and escalator in one of the entrances to the exhibition buildings.

LEVEL INDICATORS, ETC.

It is not possible to see the position of the sections from the control room and therefore a system of level indicators N is arranged in the control room, facing the operator. These indicators are operated by rams C attached to the sections and working in steel cylinders which pass down into the main stilt pits. There are two rams and cylinders to each section, located at the two stilts under the same cross girder. The raising and lowering of a section fills or discharges two tanks in the control room behind the appropriate indicator N, and the level of the displaced water is shown by floats in two glass tubes on the front of the indicator. These floats show the exact position of the platform throughout its movement. The indicator shows the relative height of the two sides of the section and this can readily be adjusted and maintained level by regulating valves situated in the control room.

For various purposes watertight doors are provided in the sides of the pool, and as these of necessity open into the pool, a system of electrical indicators U is provided in the control room to show whether any of the doors are open.

The success of an installation such as this must depend to a great extent upon the accuracy of the setting out and lining up of the various parts during construction on site, therefore it is of interest to note that the first time the platforms were moved from the positions in which they had been erected, all guide rollers operating in the channels in the sides of the pool were quite free and could be turned by hand in any position throughout the full travel, although only $\frac{1}{8}$in. clearance had been arranged on either side of the rollers and their channel paths.

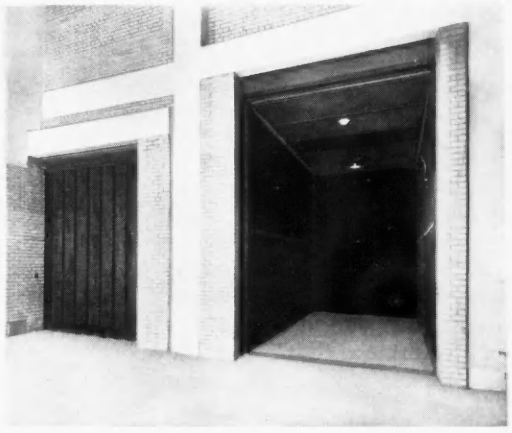


Fig. 8.—"Express-S.M.S." goods and lorry lifts.

It will be realized from the foregoing description that there are many unique features in the design and construction of the adjustable floor, and it should be added that it is the largest of its kind in the world.

* * * *

Other sections of the equipment for which the G.E.C. was responsible, include the lift and escalator equipment, of which it is proposed to publish a description in the next issue of the *G.E.C. Journal*. Two views of this equipment are shown in figs. 7 and 8.

Secondary-Electron Emission from Complex Surfaces.

By L. R. G. TRELOAR, B.Sc., F.Inst.P.
Research Staff of the M.O. Valve Company, Limited, at the G.E.C. Research Laboratories, Wembley, England.

The secondary emission from metals on whose surfaces foreign substances (e.g. electropositive metals) have been deposited to various thicknesses up to a few atomic layers has been studied. It is shown experimentally that for sufficiently thin films of the contaminant the secondary emission for a given base metal depends only on the work function of the surface, and not at all on the nature of the contaminant. The form and magnitude of the variation of secondary emission with work function agree with those calculated from the energy-distribution of secondary electrons. From a study of thicker films information is obtained concerning the mean depth of liberation of secondary electrons. The significance of the results in connexion with more complex secondary-emitting materials is discussed.

This article was originally given as a paper before the Physical Society and was subsequently published in their Proceedings.

1. INTRODUCTION.

THE possibility of making use of secondary-electron emission to obtain an amplification of electronic currents has led to a search for materials having high secondary-emission coefficients. Thus it has been found that certain metallic oxides, after treatment with alkali metal vapours, yield secondary-emission coefficients very much higher than any that have been obtained from clean metals. One of the best of these emitters is caesium on caesium oxide on silver, formed by heating oxidized silver at 200° C. in caesium vapour. This material, which is frequently employed as a photoelectric cathode, has been found by Penning and Kruithof[1]* to give a secondary-emission coefficient of between 8 and 10 at 500 volts, and similar values have been reported by other workers.

It is clear that the materials which give these high secondary-emission values have also very low work functions. It is probable, therefore, that the work function must be regarded as one of the fundamental physical factors by which the magnitude of the secondary-emission coefficient is determined. But it is not necessarily the only factor. It is the purpose of the present investigation to determine to what extent changes of work function, unaccompanied (so far as this is possible) by other changes, affect the secondary-emission coefficient.

2. METHOD OF TREATMENT.

The work function of a material may be changed by depositing on its surface a thin film of a different material. Thus, for example, the work function of tungsten may be reduced by several electron-volts by the adsorption on its surface of a barium layer less than one atom thick, and the thermionic emission is increased by a large factor as a result of the reduction in the energy which an electron is required to possess in order to pass through the surface.

When a metal is bombarded with electrons the secondary electrons, which originate beneath the surface [2], must lose energy in passing through the surface, in exactly the same way as the thermally emitted electrons. It is to be expected that, in general, there will be some secondary electrons approaching the surface from within which have insufficient energy to escape; these electrons will fall back into the interior of the metal. The relative number of such electrons will clearly depend on the work function, becoming smaller as the work function is reduced. We should therefore expect the relative number escaping, *i.e.*, the secondary-emission coefficient, to increase if the work function of the metal is reduced, for example, by the presence of an adsorbed layer of foreign atoms.

Furthermore, given a knowledge of the energy-distribution of the secondary electrons, it should be possible to calculate how the relative number of electrons escaping will be affected by a given change in the work function.

This calculation is made in the following pages, and the resulting relationship between secondary emission and work function is compared with that found experimentally for a metal contaminated with different substances.

3. THEORETICAL EXAMINATION OF THE RELATION BETWEEN SECONDARY EMISSION AND WORK FUNCTION.

The General Case. The argument outlined in the preceding paragraph, which will now be devel-

* For this and subsequent references see list at end of this article.

oped quantitatively, depends for its validity upon the assumption that the adsorbed film itself neither absorbs primary electrons nor emits secondary electrons. Any effect which it has on the secondary-emission coefficient will be considered to take place solely through the agency of the accompanying changes in work function.

The energy corresponding to the component of velocity normal to the surface will be referred to as the *normal energy* of the secondary electrons. In considering the effect of the work function on the energy of the escaping secondary electrons it is the normal energy only which will be modified, since there are no electrical forces parallel to the surface.

The normal energy distribution of the secondary electrons escaping from a clean metal may be written in the form

$$dn = f(u)\,du \qquad \ldots.(1),$$

where dn is the number of electrons having normal energy between u and $u+du$, measured in electron-volts.

The total number having normal energy greater than any positive value U will be

$$n = \int_U^\infty f(u)\,du \qquad \ldots.(2).$$

If the work function of the metal is now increased by an amount χ eV. by a suitable contamination, only those electrons which formerly escaped from the clean metal with normal energy greater than χ will now be able to escape, and the number n of such electrons will be given by

$$n = \int_\chi^\infty f(u)\,du \qquad \ldots.(3).$$

If δ_0 and δ are the secondary-emission coefficients for the clean and contaminated metal respectively, it follows that

$$\frac{\delta}{\delta_0} = \frac{\int_\chi^\infty f(u)\,du}{\int_0^\infty f(u)\,du} \qquad \ldots.(4).$$

It is therefore possible by means of equation (4) to calculate the effect of an increase of work function on the secondary-emission coefficient, provided that the normal energy distribution of the secondary electrons from the clean metal is known.

The effect of a reduction of work function, with which this paper is mainly concerned, cannot be calculated with the same accuracy, since it is necessary to extrapolate the distribution function represented by equation (1) into the region of smaller values of energy, for which u is negative. (The quantity u in equation (1) represents the energy of the electrons outside the metal. An electron whose energy within the metal is less than the minimum energy which it must possess in order to escape by an amount u may therefore be said to possess an energy $-u$.) If such an extrapolation can be made, the secondary-emission coefficient of the contaminated surface may likewise be deduced from equation (4) but in this case the change of work function χ will be negative.

Application to Maxwellian Distribution. If the secondary electrons have an energy-distribution represented by Maxwell's Law, equation (1) becomes

$$dn = Ae^{-\alpha u}\,du \qquad \ldots.(5),$$

where A and α are constants. Substitution in (4) gives

$$\frac{\delta}{\delta_0} = \frac{A}{\alpha} e^{-\alpha\chi}$$

or

$$\log_{10}\delta = C - b\chi \qquad \ldots.(6),$$

where C and b are constants, δ_0 being fixed. If in this equation χ is taken as the independent variable, it is seen that for a given metal, variously contaminated, the logarithm of the secondary-emission coefficient varies linearly with the work function.

An equation equivalent to equation (6) has been derived theoretically by Sixtus[3] for the special case of a Maxwellian distribution of energy. Sixtus also measured the secondary-emission coefficient and work function for a thoriated tungsten filament in different states of activation. He found the equation to be applicable over a limited range of work functions, but the coefficient b was found to vary greatly with the energy of the primary electrons. These results will be considered in greater detail later.

Derivation of Normal Energy-distribution. Before considering the applicability of the results deduced in the preceding sections, it is necessary to examine the available data on the energy-distribution of secondary electrons. The first point to be noted is that there are no experimental data for the *normal* energy-distribution. Such measurements as have been made on the energy-distribution fall into the following two classes.

(*a*) The retarding potential method. In this method the secondary electrons from a target are collected by a chamber (usually spherical) surrounding it, to which negative potentials with respect to the target are applied. Provided that the chamber is large compared with the target, this method gives the integral of the *total* energy-distribution curve, *i.e.*, the number of electrons having total energy greater than any given value.

(*b*) The magnetic-spectrum method. In this method a beam of secondary electrons from a target is deviated by a magnetic field, and the total energy-distribution is obtained directly.

The most accurate work on the total energy-distribution is probably that of Haworth, who has

obtained curves for molybdenum [4] and columbium [5] by method (*b*). His data for molybdenum will be taken as a basis for the calculations which follow. Curve *a* in fig. 1 is taken from Haworth's paper, and shows the total energy-distribution curve up to an energy of 35 eV. This portion of the curve was found to be nearly independent of the primary energy for primary energies greater than 37 eV.

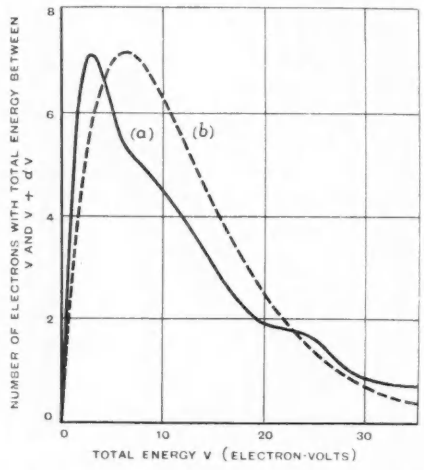


Fig. 1.—Total energy-distribution curves : (a) Secondary electrons (Haworth), (b) Maxwellian.

In order to be able to derive the normal energy-distribution from the total energy-distribution, it is necessary to make some assumptions about the distribution in angle of the secondary electrons. On this point the experimental evidence is not conclusive, but it suggests that the number of secondaries emitted per unit solid angle in a direction making an angle θ with the normal is proportional to $\cos\theta$ [6]. This law will be assumed to be true, and it will be assumed also to apply to any fraction of the emitted electrons having total energies within any given range. The second of these assumptions is equivalent to the statement that the energy-distribution function is the same for beams of electrons emitted in any direction.

If now we suppose the number of electrons emitted, independently of direction, with energy between V and $V + dV$ to be given by

$$dN = F(V)\,dV \qquad \ldots.(7),$$

then, from the cosine law, the number having total energy within this range which are emitted at angles to the normal greater than θ may readily be shown to be $dN\cos^2\theta$. Of the electrons having total energy between V and $V + dV$ these, and these only, have normal energy less than $V\cos^2\theta$. If we now write $V\cos^2\theta = U$, where U is a constant, we obtain for the number having total energy between V and $V + dV$ and normal energy less than U, where $V > U$,

$$dN\cos^2\theta = dN.U/V = U.F(V)\,dV/V \qquad \ldots.(8),$$

from equation (7).

The total number having normal energy less than U and any value of total energy greater than U is found by integrating (8) from U to ∞, i.e.

$$U\int_U^\infty \frac{F(V)\,dV}{V} \qquad \ldots.(9).$$

And of course all those electrons for which $V < U$ have normal energy less than U. Adding this quantity to equation (9), we find that the total number having normal energy less than a given value U and any value of total energy is

$$\int_0^U F(V)\,dV + U\int_U^\infty \frac{F(V)\,dV}{V} \qquad \ldots.(10).$$

From this it may readily be deduced that the number N_U having any value of total energy and normal energy greater than U is given by

$$N_U = \int_U^\infty F(V)\,dV - U\int_U^\infty \frac{F(V)\,dV}{V} \qquad \ldots.(11).$$

Since N_U in equation (11) and n in equation (2) both represent the number of electrons having normal energy greater than U, the right-hand sides of these two equations must be equal, and the relation between secondary-emission coefficient and

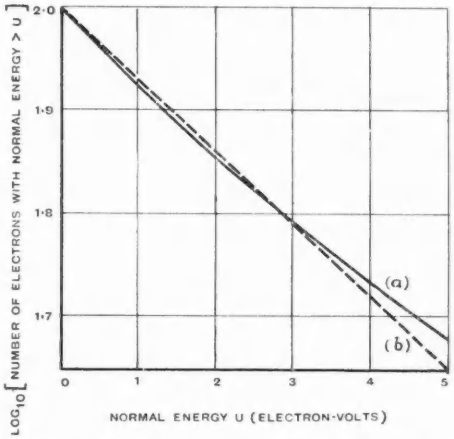


Fig. 2.—Integrals of normal energy-distribution curves : (a) Secondary electrons, (b) Maxwellian.

work function is given by an equation analogous to equation (4), namely

$$\delta/\delta_0 = N_\chi/N_0 \qquad \ldots.(12).$$

where χ is the increase of work function produced by a contamination.

Starting from Haworth's curve for the total energy-distribution of secondary electrons for a primary energy of 150 eV., and determining the values of the integrals in equation (11) graphically, we obtain the full curve shown in fig. 2 when $\log_{10} N_U$ is plotted against U. The portion of the

curve shown covers a range of 5 e*V*., which includes 52 per cent of the secondary electrons.

It will be observed that the curve thus obtained approximates closely to the Maxwellian form given by $\log_{10}N_U = A - bU$. The value of b which best fits the curve over the range shown is found from the slope of the dotted line in fig. 2 to be 0·070 (eV.)$^{-1}$. This should therefore also be the value of b in equation (6), representing the relation between secondary-emission coefficient and work function, in the case of contaminated molybdenum. Fig. 1 (*b*) shows a Maxwellian distribution of total energy corresponding to this same value of b. It is noteworthy that the integral of the normal energy-distribution curve approaches the Maxwellian form more nearly than does the total energy-distribution.

Deductions from the Foregoing Theory. The experiments to be described were carried out with the object of testing the applicability of the foregoing theory to the case of a contaminated metal surface. The following four main results are to be expected: (1) A linear relationship should exist between $\log_{10}\delta$ and χ. (2) The constant b, representing the rate of change of $\log_{10}\delta$ with χ, should have the value 0·070 (eV.)$^{-1}$ in the case of molybdenum. (3) For a given metal, the value of b should be independent of the nature of the contaminant. (4) For a given metal, the value of b should be nearly independent of the energy of the primary electrons.

4. EXPERIMENTAL METHOD.

In carrying out the experiments, use was made of the method of measuring secondary emission from filaments described by the author in an earlier paper[7]. A valuable feature of the method is that it permits of the measurements of changes in the relative contact potential of the filament whose secondary emission is being studied, with respect to a clean tungsten filament. The changes of contact potential give a measure of the changes in work function.

The cross-section of a typical tube is shown in fig. 3 (*a*), the main dimensions being the same as those given in the paper previously referred to. The tungsten cathode *C* provides the primary current, *T* is the target (secondary-emitting) filament, and *B* an extra filament to provide the contamination, *e.g.*, an oxide-coated nickel filament. This filament

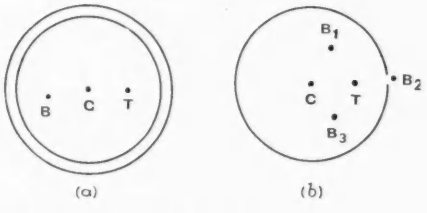


Fig. 3.—Cross-sections of electrode systems.

was maintained at cathode potential during the secondary-emission measurements.

The Contact-potential Measurements. The measurement of the contact potential was carried out in the following way. The cathode was maintained at a temperature such that a saturated thermionic emission current of 5 mA. was drawn to the anode and grid, when these two electrodes were at 100 volts positive potential with respect to the cathode. The target current was then measured, as a function of the target potential, with respect to the cathode, over a range of a few volts above that at which it first assumed a measurable value. The curve obtained under these conditions had a considerable linear portion, which, when extrapolated, cut the zero current axis at a point x. The difference between the value of x for the uncontaminated target and its value for any state of contamination was taken to be equal to the contact potential-difference between the clean and contaminated surfaces. It is also equal to the difference between their work functions.

It was found that the value of x obtained for any state of the target was not affected by changes of a few volts in the potential applied to the anode and grid. Any changes occurring in the contact potential-difference between these electrodes and the cathode could therefore be neglected.

The value of x obtained in this manner was referred to the potential of the tungsten cathode. In order that changes in x should give a true measure of the changes in contact potential of the target, it was necessary to ensure that the cathode was always in the same condition when the measurement was carried out. Since the cathode, as well as the target, became contaminated during the experiments, it was therefore necessary to remove this contamination by heating the cathode to a high temperature before taking each set of readings.

5. EXPERIMENTAL RESULTS.

The experimental results for films of barium on molybdenum, and of barium, thorium and oxygen on tungsten will now be presented, and a comparison of the results with the theoretical expectations will follow. An examination of some of the effects produced by comparatively thick films will then be made.

Barium (from an Oxide-coated Filament) on Tungsten. Fig. 3 (*a*) shows the disposition of the electrodes in this experiment. *T* was a tungsten filament 0·104 mm. in diameter and 50 mm. long, *C* was a similar filament 12 mm. long, and *B* was a nickel wire 0·18 mm. in diameter and 50 mm. long, coated with a mixture of barium and strontium carbonates in equal molecular proportions. During the pumping of the tube the filament *B* was heated to convert the carbonates to oxides, and eddy-

current heating and barium gettering were carried out before sealing off the tube. (A slight modification of the original design, introduced during the course of the work, consisted in making the grid free to slide at one end instead of rigidly fixed. This precaution was taken to prevent distortion of the grid during the eddy-current heating).

In carrying out the experiment, the target and cathode were first cleaned by heating at 2800° K. for a few minutes, and the contact potential and secondary-emission coefficient for 300 volts bombarding potential were measured. The result of these measurements is indicated by the point *A* in curve *a*, fig. 4, which shows the relation between $\log_{10}\delta$ and the change in the work function of the target. The oxide-coated filament was then heated at about 1400° K. for a short time, and after the cathode had been cleaned the measurements were repeated. This second point is shown at *B*. The deposition of barium on the target from the oxide-coated filament had caused a reduction in the work function and an increase in the secondary emission. Successive repetition of these operations gave the points indicated by crosses, the final point being *C*.

On now heating the target at successively higher temperatures so as to re-evaporate the barium, the points marked by circles were obtained. The final condition of the target (point *D*) was nearly the same as its initial condition.

Barium (from an Oxide-coated Filament) on Molybdenum. This experiment was in all respects similar to that described for tungsten, except that points were obtained only during the later stages of evaporation of barium from the target. The results of this experiment, which is shown in curve *b*, fig. 4, have already been published in *Nature*[8].

Thorium on Tungsten. In this experiment the target was a thoriated tungsten filament of diameter 0·1 mm. The contaminant, thorium, was brought to the surface of the filament by diffusion from within the metal. In curve *a*, fig. 5, the point *A* represents the fully activated filament. The remaining points were obtained during deactivation at successively higher temperatures. The final point *B* represents a clean (or very nearly clean) surface of tungsten, and it is noteworthy that the value of δ for this condition is very nearly the same as that found for pure tungsten, point *A*, fig. 4 (*a*). A similar experiment has been performed by Sixtus[3], and it is interesting to compare his results, which are reproduced in curve *b*, fig. 5, with the author's.*

Oxygen on Tungsten. The tube used in this experiment had attached to it a side tube containing a small quantity of potassium permanganate. After measurement of the secondary-emission coefficient at a primary voltage of 300, and of the contact potential of the target, which was of tungsten, the temperature of the target was raised to 1500° K. and oxygen was admitted by heating the permanganate. After the gas had been absorbed by the getter, measurements were made on the oxygenated filament.

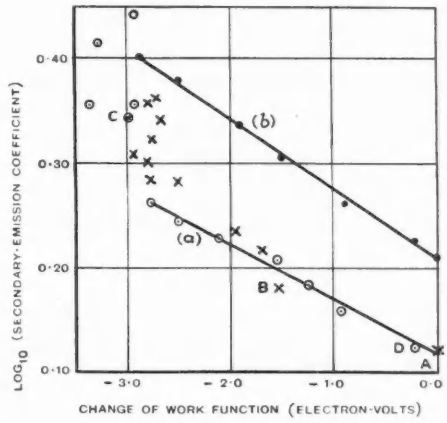


Fig. 4.—Relation between secondary-emission coefficient and work function: (a) Barium (from oxide-coated filament) on tungsten, x deposition, ⊙ evaporation. (b) Barium on molybdenum. Primary-electron voltage 300.

The following results were obtained:

For clean tungsten δ	= 1·31.
For oxygenated tungsten δ	= 1·06
Change of work function on oxygenation	= 1·78 eV.

The value for the contact potential difference between clean and oxygenated tungsten is in close agreement with Reimann's value of 1·75 V.[9]

6. DEDUCTIONS FROM THE EXPERIMENTS.

The results for barium on tungsten, barium on molybdenum, and thorium on tungsten prove that, provided that the contaminating film is not too thick, there exists a linear relationship between $\log_{10}\delta$ and χ, in accordance with the theoretical expectation. The region representing thicker films in fig. 4 (*a*) will be considered later.

The slopes of the curves, giving the values of *b* in equation (6), are given in table 1 for the primary voltages indicated.

TABLE 1.

Values (eV^{-1}) of *b* for various contaminated surfaces.

Voltage (V.)	300	150	35
Barium on molybdenum	.067	.057	.050
Barium on tungsten	.052	.060	.043
Thorium on tungsten	.053	—	—
Oxygen on tungsten	.052	—	—

From these figures it is clear that for a given value of the work function and for the different

* The author regrets that at the time of reporting his first results to "*Nature*" he was not aware of the work of Sixtus.

contaminations on tungsten, the secondary emission is independent of the nature of the contamination. The value of b is found to change only to a relatively slight extent with variations in the primary voltage. The variations in table 1 are hardly outside the experimental errors.

These variations do not accord with the data given by Sixtus for thoriated tungsten[3]. He found the value of b to fall considerably as the primary voltage was increased from 200 to 800. Thus, at 400 V., for example, its value was 40 per cent lower than at 200 V. No such large variation is to be expected from the theoretical considerations brought forward earlier in this paper.

7. COMPARISON OF THEORETICAL AND EXPERIMENTAL VALUES OF b.

It has been shown that the experimental results are concordant with the main predictions of the theory. The quantitative comparison between the theoretical and experimental values of b remains to be made.

The theoretical value was 0·070 (eV.)$^{-1}$ for molybdenum at 150 eV. primary energy.

An examination of the experimental data gives reason to believe that the difference between the 150–V. and 300–V. values for molybdenum shown in table 1 is fortuitous. The mean of these two values will therefore be taken as the most probable experimental value of b for 150–V. primaries. The value thus obtained is 0·062 (eV.)$^{-1}$, which is about 12 per cent less than the theoretical value.

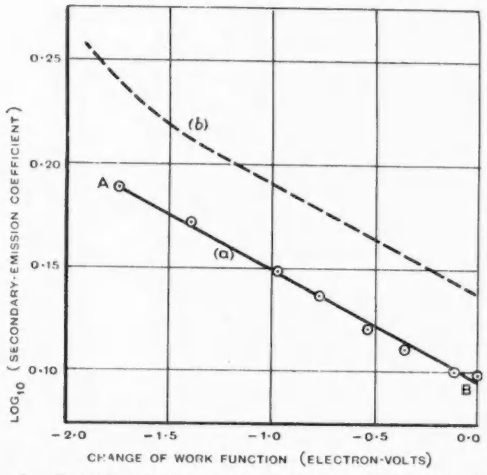


Fig. 5.—Relation between secondary-emission coefficient and work function for thoriated tungsten: (a) Author's results, (b) Sixtus's results. Primary-electron voltage 300.

It will be remembered that the theoretical value was arrived at from the slope of the line which best fitted the integrated normal-energy-distribution curve over an arbitrary range of positive energies. The experiments are concerned with the region of negative energies (as defined in § 3) covering the approximate range 0 to −3 eV. A more exact comparison of the theoretical and experimental values therefore necessitates finding the mean slope of the extrapolated curve of fig. 2 over the range 0 to −3 eV. This extrapolation, though it cannot be made very exactly, yields the value 0·085 (eV).$^{-1}$ for b, a value which should be nearer the truth than 0·070. With this revised value of b, the experimental value is 27 per cent low.

The experimental errors involved in the determination of b are rather large. The theoretical value involves the errors in the measurement of the energy-distribution and the error introduced by the extrapolation to negative energies. Even when all these errors are considered, however, it is difficult to account for a difference of 27 per cent.

In considering the possible causes of this discrepancy, it must be remembered that the validity of the assumption of a cosine law of distribution in angle of the secondary electrons cannot be regarded as established beyond doubt.

8. EFFECTS WITH THICK FILMS.

Our interest thus far has been confined to the thin-film contaminations for which the linear relationship between $\log_{10}\delta$ and χ is applicable. A special experiment was carried out with the object of investigating the thick-film region. The oxide-coated filament, previously used as a source of barium, was replaced by a nickel-barium alloy wire containing about 0·6 per cent of barium. It was hoped that the barium obtained from this source would be purer than that from an oxide-coated filament, since it is known that an oxide-coated filament gives off oxygen as well as barium, the relative amount of oxygen depending upon the amount of ageing to which the filament has been subjected, as well as on its temperature[10].

In order to secure a fairly uniform deposition of barium over the surface of the target, three nickel-barium wires B_1, B_2 and B_3, fig. 3 (*b*), were arranged symmetrically round the target T. To avoid undue complication the grid was omitted, the primary current calibration (required for the measurement of δ) being taken from the dimensionally similar tubes already described, in which the grid was present.

The relation between $\log_{10}\delta$, at a primary voltage of 300, and χ for this tube is shown in fig. 6, which is drawn in a manner comparable with fig. 4 (*a*). The portion AB of this curve represents the thin-film region, whilst BC represents the thick-film region. The thin-film portion of the curve falls along a straight line whose slope is 0·052 (eV.)$^{-1}$. It is interesting to observe that whereas the thin-film portions of the curves of fig. 4 (*a*) and fig. 6 have exactly the same slope, the thick-

film portions are entirely different. The thick-film points lie above the linear portion of the curve for barium derived from an oxide-coated filament, and below for barium derived from a nickel-barium alloy. This difference must be attributed to the presence of oxygen, as well as barium, in the former case. This also accounts for the greater maximum reduction of work function produced when the source of the contamination is an oxide-coated filament. It may be mentioned that these differences are quite typical and have been observed with a number of different tubes.

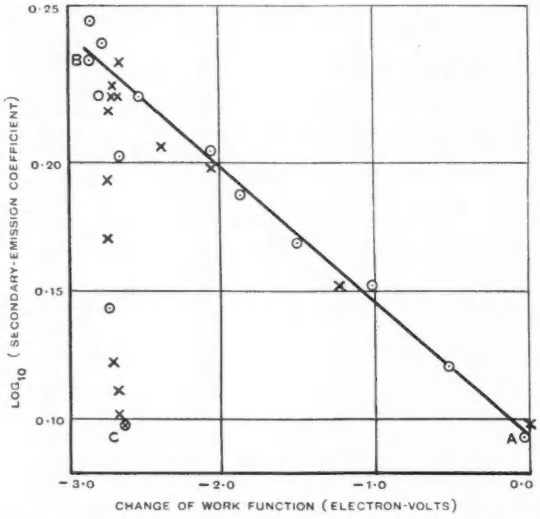


Fig. 6.—Relation between secondary-emission coefficient and work function. Barium (from nickel-barium alloy) on tungsten: x deposition, ⊙ evaporation. Primary-electron voltage 300.

In deriving the theoretical expression for the effect of variations of work function on secondary emission, it was assumed that the contaminating film neither absorbed primary electrons nor emitted secondary electrons. It would appear that the region *BC* in fig. 6 represents thicknesses of film for which this assumption is no longer true, and that for points in this region the secondary electrons originate at least partly in the barium film itself.

The data from which fig. 6 was obtained are represented in a different manner by curve *a*, fig. 7. This figure shows the variation of the secondary-emission coefficient with the total time of deposition of barium from the nickel-barium wires. An independent experiment showed that the rate of evaporation of barium was practically constant for the temperature and time used. Hence, the time of deposition gives a measure of the relative amount of barium present on the target.

The rising portion of this curve represents the thin-film region, in which the secondary electrons originate almost entirely in the tungsten. The final portion shows a tendency for the secondary emission to approach a constant value and indicates that here the effect of the underlying tungsten is becoming negligible. In the intermediate (falling) portion of the curve the tungsten and the barium both contribute to the secondary emission.

9. THE DEPTH AT WHICH SECONDARY ELECTRONS ORIGINATE.

At the point *M*, fig. 7, where the secondary emission is half-way between the thin-film and thick-film values (the work function being approximately constant) the secondaries probably originate in about equal numbers from the tungsten and barium films. The thickness of film corresponding to this point may therefore be taken to be approximately equal to the mean depth at which the secondary electrons originate.

An attempt will now be made to compute this depth. This may be found in terms of the thickness of film which gives the maximum thermionic emission or minimum work function (subsequently referred to as the *optimum thermionic layer*) by reference to the change in work function for different times of barium deposition, curve *b*. This curve may be compared with Becker's[11], which shows how the reduction of work function varies with the relative surface concentration of barium on tungsten. The absence of a clearly defined minimum in the author's work-function curve is probably associated with non-uniformity of the deposit, as a result of which different portions of the target attained the minimum work function at different times. In Becker's experiments such non-uniformities were probably reduced by diffusion of barium over the surface of the tungsten when the filament was heated. However, by considering the rate of fall of work function in the early stages of the deposition, it is possible to obtain a fairly accurate indication of the time at which the optimum thermionic thickness was effectively reached. This time comes out at 1·3 min. The point *M* therefore corresponds to 2·8 optimum thermionic layers.

If we can now translate depths in terms of optimum thermionic layers into depths in terms of atomic layers, we shall be able to arrive at the mean depth at which the secondary electrons originate. Unfortunately the thickness of film, or surface concentration of barium atoms corresponding to one thermionic layer, has not been experimentally determined. For caesium on tungsten the optimum thermionic layer has been found by Langmuir[12] to be 0·67 of a monatomic layer, but there is no reason to believe that the same value will apply for barium on tungsten. From theoretical considerations de Boer[13] has estimated the optimum covering for barium to be 0·29 of a monatomic layer. Perhaps the best that can be done is to take a value of 0·5 for this quantity. The mean depth

at which the secondary electrons originate, according to this assumption, is 1·4 atomic layers.

A correction of this value is necessitated by the fact that the primary electrons strike the target at various angles of incidence. The mean angle of incidence, under the conditions of measurement (*i.e.*, with target potential 300 and anode potential 450), may be taken to be the same as if the electrons remain undeviated from their rectilinear paths by the presence of the target; its value is therefore about 30° to the normal. On the basis of Bruining's work[2] on the effect of angle of incidence on the mean depth at which secondary electrons are liberated, the depth for normal incidence will thus be increased by the factor sec. 30° compared with the depth for 30° incidence. The application of this correction to the value obtained above gives 1·6 atomic layers for the mean depth at which the secondary electrons originate, with a primary voltage of 300 and normal incidence. This figure may be in error by a factor of about 2, on account of the uncertain value of the optimum thermionic layer.

From his experiments Bruining[2] has calculated the product of the absorption coefficient for secondary electrons in nickel and the mean depth at which they originate to be 0·45 for 300-V. primary electrons. He then substitutes Becker's value[14] of $1{\cdot}5\times10^{6}$ for the absorption coefficient for electrons of energy equal to the mean energy of the emitted secondaries, and obtains the value 30 angstroms for the mean depth at which the secondary electrons originate. This figure, which represents about 14 atom-layers of nickel, is of a different order of magnitude from that found in the present work.

10. OTHER WORK ON COMPLEX SURFACES.

It has been shown in § 6 that the effect of a change of work function on the logarithm of the secondary-emission coefficient is nearly independent of the energy of the primary electrons. On this basis it is possible to describe qualitatively how the shape of the curve representing the logarithm of the secondary-emission coefficient as a function of the primary energy will be affected by the deposition on a metal surface of increasing quantities of a contaminant.

So long as the contamination satisfies the thin-film criterion the change of secondary emission will be determined solely by the change in work function, hence the change in log δ will be the same for all values of the primary energy. In this region, therefore, the successive degrees of contamination will be manifested by a displacement of the original curve parallel to the axis of log δ, without alteration of shape. When the thickness of the film becomes sufficient for the effect of the underlying metal to be neglected, a curve will be obtained representing simply the secondary emission of the contaminant in bulk. In the intermediate region, between the thin and very thick films, the shape of the curve will in general, differ from that for either of the simple materials.

These expectations are substantially verified by the experimental curves of Copeland[15] showing the logarithm of the secondary-emission coefficient as a function of the primary voltage, for a metal on which were deposited successive amounts of a contaminant. In each of the three cases studied,

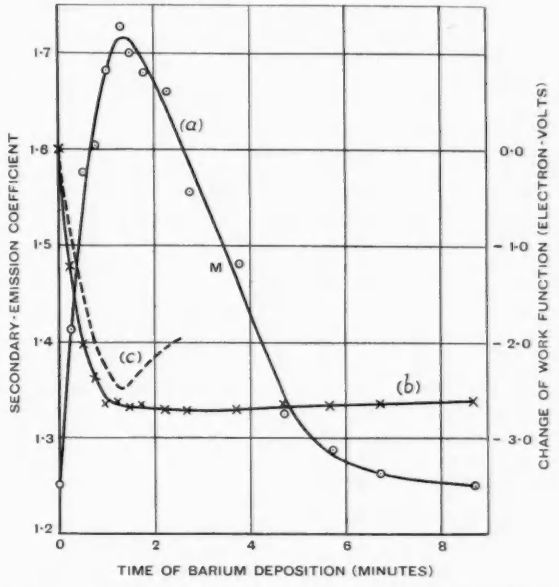


Fig. 7.—Variation (a) of secondary-emission coefficient and (b) of work function, with amount of barium on surface of tungsten. (c) Becker's work-function curve.

the first effect of the contamination was to displace the curve parallel to the axis of log δ. Thus, in the case of aluminium contaminated with platinum a reduction of $\log_{10}\delta$ by about 0·15 took place before the shape of the curve became definitely changed. Since the work function of platinum is higher than that of aluminium, a reduction in log δ would be expected as a result of the deposition of the former metal on the latter. An opposite effect was observed when calcium was deposited on gold; this again is to be expected from consideration of the work function.

Since the thickness of film for which the simple work-function effect ceases to apply is related to the depth at which the secondary electrons are liberated, and since this depth increases with the energy of the primary electrons, it would be expected that the shape of the curve typical of the underlying metal would persist to a greater thickness of film at the higher than at the lower primary energies. This expectation also is borne out by Copeland's results.

Whilst Copeland's interpretation of his experiments is concerned chiefly with what has been described in the present work as the "thick-film" region, it seems that his generalization to the effect that the major portion of the observed changes in secondary emission must be ascribed to some other cause than the variation of work function tends rather to underestimate the importance of a factor which has considerable significance in any interpretation of phenomena of this kind.

11. THE SIGNIFICANCE OF THE WORK-FUNCTION EFFECT.

The general result of the investigation which has been described may be stated in the following terms: *For any metal whose work function is varied by the deposition on its surface of a thin film of a foreign substance, changes in secondary-emission coefficient are determined solely by the accompanying changes in work function. The magnitude of such changes can be predicted if the energy-distribution of the secondary electrons is known.*

There is no reason to doubt that this law can be generalized to include non-metals as well as metals. On the other hand, it does not account for the changes in secondary emission produced by a thick-film contamination, neither does it give any information about the relative secondary-emission coefficients of different specific materials.

The following discussion, which is admittedly speculative, suggests how the knowledge already gained may be brought to bear on the problems raised by some of the highly complex secondary-emitting materials referred to in § 1.

We may begin by considering what is the maximum secondary emission obtainable from a simply-contaminated metal. The secondary-emission coefficient which would be given by tungsten, for 300-V. primary electrons, if its work function were imagined to be reduced to zero by a thin-film contamination would be 2·3, and that for molybdenum under the same conditions would be 2·9. From the knowledge that the energy-distribution curves for secondary electrons for the dozen or so metals that have been studied in this respect are all quantitatively similar, combined with the fact that the range in the secondary-emission coefficients of the clean metals which have been reliably examined is not very great, it is possible to predict that the highest secondary-emission coefficient obtainable from any metal having a thin-film contamination will not be much more than 3·0 at 300 volts, however much its work function is reduced.

It is known that a number of complex substances yield secondary-emission coefficients much in excess of this value. As a typical case caesium on caesium oxide on silver, referred to in § 1, may be cited. The secondary-emission coefficient for this material at 300 V. may be as high as 8·0. There is nothing in the preceding work which gives any hint of the reason for such a high value.

If, however, we regard the material as a thin-film contamination of caesium on caesium oxide, and if we assume that the uncontaminated caesium oxide would have a very much higher work function than the activated surface, there are two interesting possibilities. It may be (*a*) that the secondary-emission coefficient for the uncontaminated caesium oxide is about the same as that for a metal having the same work function, but the rate of change of secondary-emission coefficient with work function is much greater; or (*b*) that the rate of change of secondary-emission coefficient with work function is about the same as for a metal, but the secondary-emission coefficient for the uncontaminated caesium oxide is very much greater than that for a metal having the same work function. (*b*) is unlikely to be true, since no oxides in the uncontaminated state have been reported as having very much higher secondary-emission coefficients than the pure metals. If, however, (*a*) is true, it follows that the average energy of the secondary electrons from caesium oxide is very much lower than that of the secondary electrons from a metal. This is a matter which could be investigated experimentally.

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The Lighting of the Indian Aerodromes on the British Empire Air Routes.

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Fig. 1.—Control building at Delhi, with 3 kW neon beacon on roof.

CONSIDERABLE progress has been made by the Government of India in the constructing and equipping of the aerodromes on the portion of the England to Australia air route between Karachi and Rangoon.

Fig. 2 gives a sketch map of India showing the actual air route and landing grounds concerned. The distance between Karachi and Rangoon is approximately 2,400 miles, which is about one third of the total distance from London to Singapore. The project, which includes the installation of aerodrome lighting equipment at all landing grounds, thus materially assists the scheme of day and night flying which it is desired to establish throughout the route. While the main aerodromes are naturally near important towns, some of the emergency landing grounds are peculiarly inaccessible and present unusual difficulties in the erection of electrical equipment.

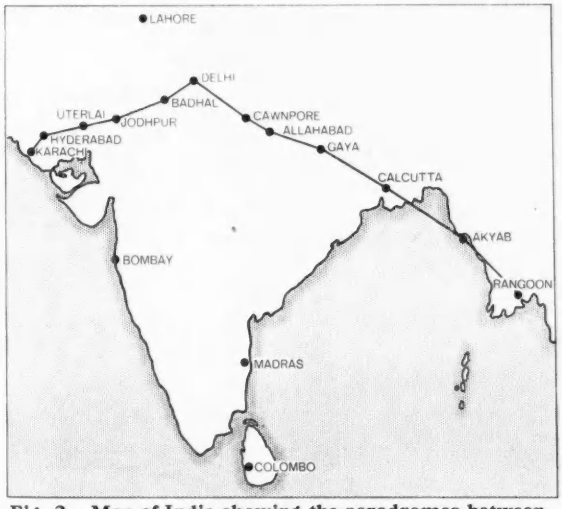


Fig. 2.—Map of India showing the aerodromes between Karachi and Rangoon on the England to Australia air route.

In this article it is proposed, first, briefly to outline the events which led to the development of the present scheme; secondly to describe the scheme itself, and lastly to give some details of the actual apparatus and its installation.

ORIGINAL AIR-MAIL SERVICE.

The original air service from England to India began in 1929, when the Indian Air Mail first reached Karachi. Thence mails were carried by rail all over India, and while it took seven days to fly from London to Karachi, it took a further three days for mails to reach Calcutta by train, thus taking a total of eleven days, allowing for collection and delivery.

Shortly after this, however, the Delhi Flying Club arranged to carry mails from Karachi to Delhi, and this was carried out with commendable regularity. It may be mentioned in passing that the Delhi Flying Club is probably the only concern of its kind which has ever been awarded a Government mail contract.

Unfortunately, the club soon found itself unable to carry on the contract, and it was not until 1933 that Indian Transcontinental Airways, a concern owned jointly by the Government of India and Imperial Airways, extended the route to Delhi and then Calcutta.

In the meantime, the Government and certain

private individuals had become aware of the immense advantages aviation could provide in India. When it is realised that India has an area as large as that of all the countries of Europe added together except Russia, and that industrial centres are few and far between, these advantages are at once apparent.

As a result, in April, 1931, the Government of India issued tenders and actually placed a contract for lighting the route between Karachi and Delhi, but the industrial depression intervened and for reasons of economy, the scheme was temporarily abandoned. It was not until January, 1935, that the scheme was revived and the present Karachi-Rangoon scheme was initiated. In the meantime, aerial traffic had increased enormously, the Imperial Airways service running bi-weekly each way to Calcutta and weekly to Singapore, and the K.L.M. and Air France companies providing weekly services.

Up to this time, the only properly equipped aerodrome was at Jodhpur, a native state mid-way between Karachi and Delhi, where lighting equipment had been installed by the state itself early in 1934. The result was that all the three air lines made a stop at Jodhpur, the lighting proving of great value when aircraft arrived late due to head winds or other causes.

Fig 3.—Cone type boundary light.

NEW AERODROME LIGHTING SCHEME.

The scheme originally devised by the Director of Civil Aviation in India not only included night landing equipment, but also the extension of landing grounds, the improvement of approaches, together with new terminal buildings, new hangars and radio equipment for the more important grounds.

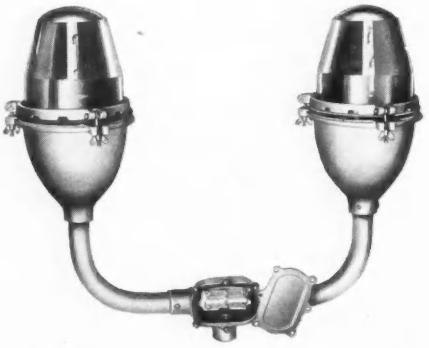


Fig. 4.—Twin obstruction light fitting.

The most important landing grounds on the route, namely, Karachi, Delhi, Cawnpore, Allahabad and Calcutta, were each to have new buildings and hangars, together with landing floodlights, beacons, illuminated wind direction and velocity indicators, boundary lights and obstruction lights. Of the remainder, floodlights were to be installed at Bombay, Gaya and Akyab, and at these and at Uterlai, Hyderabad (Sind) and Rangoon, wind indicators, boundary lights and obstruction lights were required, the Directorate arranging on the latter three grounds to use mobile floodlights which they already possessed. In addition, all cabling, switchgear and four sets of duplicate generating equipment had to be installed.

The equipment employed throughout the system was manufactured and supplied by the G.E.C., and is, as far as possible, indentical for each ground so that stocks of spare parts may be kept to a minimum.

BOUNDARY LIGHTS.

The boundary lights are all of the Cone type (fig. 3) each fed by a small transformer at 6·6 volts from a series ring main, the latter taking its supply from a main transformer. This method not only ensures that every lamp burns at the same efficiency, but affords a considerable saving in the quantity of cable required, as only a single core ring is necessary. A total of 384 boundary lights is used throughout the route.

OBSTRUCTION LIGHTS.

All obstruction lights are in the form of "twin" fittings (fig. 4) to ensure that in the event of a lamp failure at any point, the obstruction is still marked.

WIND DIRECTION INDICATORS.

The direction of the wind on the landing ground is indicated by large indicators each fashioned in the form of a T, the dimensions of each limb being 20ft. by 20ft. The top side is illuminated by forty 15-watt lamps. Such an indicator is clearly visible to a pilot at an altitude of 1,000 feet on a clear night. On each indicator is a weighted arm whose function is to return the indicator automatically to the best landing direction when the wind velocity is less than 3 miles per hour.

An illuminated wind velocity indicator is installed alongside each of the direction indicators and consists of a small windmill having 4ft. diameter vanes which are rotated by the wind and drive a vertical shaft on which is mounted a centrifugal governor mechanism. The rising of the governor arms rotates a series of cams which, in turn, tilt mercury switches. These control the electricity supply to an electric sign of the numerical type, which lies flat on the ground. Various combinations of mercury switches light up one of the

figures 0, 5, 10, 15, 20 and 25, thereby giving a direct reading of wind velocity.

LANDING FLOODLIGHTS.

Three types of floodlights are employed for different conditions, each being rated at 9 kW and using optically worked parabolic glass trough reflectors and line-filament, horizon type lamps. The three types in use are (*a*) a nine-lamp floodlight, (*b*) a three-lamp floodlight and (*c*) a three-lamp combined floodlight beacon. While it is not intended to employ shadow bars for night landing, types (*b*) and (*c*) mentioned above are so fitted in case of emergency. All these floodlights can be connected to form a balanced load across three phases. Altogether, eight nine-lamp floodlights, one three-lamp floodlight, and two floodlight beacons have been used along the route.

ROTATING ROUTE BEACONS.

Rotating route beacons (fig. 5) installed at Karachi, Cawnpore and Allahabad, are of a new type and employ a 50 volt 1500 watt grid filament lamp in conjunction with a special reflector, whose contour in one plane is a parabola, and an ellipse in the plane at right angles. This gives a main beam whose horizontal spread is about 12 degrees and whose vertical spread is about 3 degrees. The intensity is of the order of one million candle power. This beam is directed upwards at an angle of one degree above the horizon, and aircraft flying at 3000 feet can thus receive a light signal 35 to 40 miles away. Recent reports indicate that on clear nights, the beacon at Allahabad has been sighted by aircraft at a distance of 90 miles. A refractor is also incorporated which redirects some of the main beam at higher angles, in order that during bad weather the beacon may easily be discernable at various heights. A 250-watt red identification light, mounted on top of the beacon, is arranged to flash a Morse letter indentifying the aerodrome. An automatic lamp changer brings into focus a spare lamp should the main lamp fail, at the same time giving a suitable warning to the ground staff.

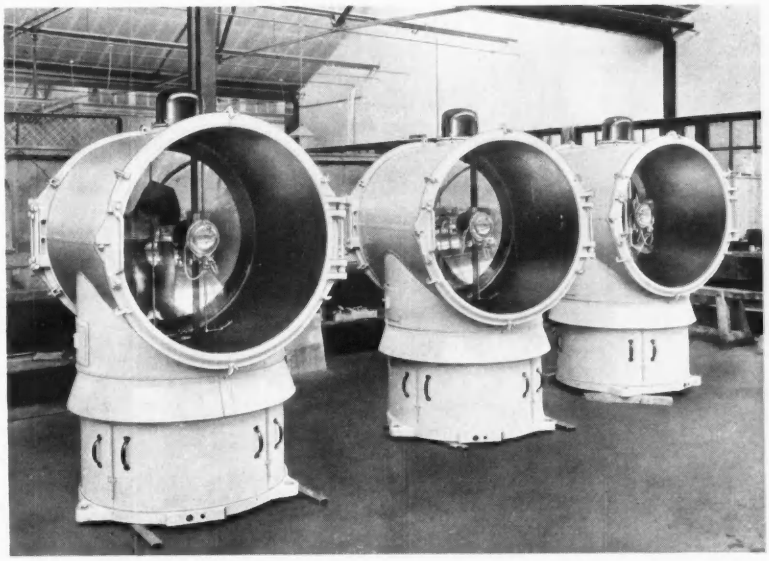


Fig. 5.—Three of the 36in. rotating beacons used on the Indian air route.

CONTROL OF EQUIPMENT.

At Karachi, Delhi, Cawnpore, and Allahabad (and also at Jodhpur) special control desks have been placed in the control tower. These desks control all

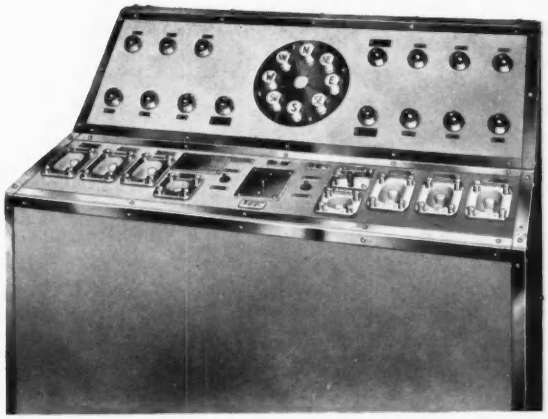


Fig. 6.—Control desk with wind direction indicator for controlling the aerodrome lighting equipment at Karachi airport.

night landing equipment, and by means of an illuminated dial (seen in the centre of the desk, fig. 6) which is operated by the wind direction indicator, the direction of the wind is indicated to the control officer, so that he can ascertain which floodlight to use for landing. At other grounds, where there is no control tower, the control equipment comprises standard ironclad switchgear which is mounted on the wall of the hangar or power house. At Calcutta, Akyab and Rangoon, a wind indicator of the type just described is incorporated.

GENERATING PLANT.

No electric supply was available at Uterlai and Gaya, and at these areodromes, duplicate generating plant has been installed. The power houses are brick buildings, with flat roofs. At Uterlai, the plant consists of two 8 h.p. Lister crude oil engines each driving a 3·5 kW 400/230 volts 3 phase, 50 cycle alternator, while at Gaya, where there are floodlights, two Lister engines each drive a 17 kW, 400/230 volts 3 phase, 50 cycle alternator. As it is only necessary to run one set at a time, no synchronizing gear is necessary, and the control panels are therefore simple in design.

Fig. 7.—The power house at Gaya, with a 9 kW floodlight beacon mounted on the flat roof.

The switchgear is arranged so that it is impossible for the native in charge to start up both generating sets together.

INSTALLATION.

The whole of the installation work was undertaken by the Calcutta Branch of the General Electric Co. (India) Ltd., a subsidiary company of the G.E.C.

The rates for unskilled labour vary enormously throughout India, as also do the facilities for obtaining transport of material to site from the railway, local accommodation for supervisors and men, and in the case of Uterlai, supplies of food. In order to obtain an adequate knowledge of these local conditions, a complete survey of every landing ground was made.

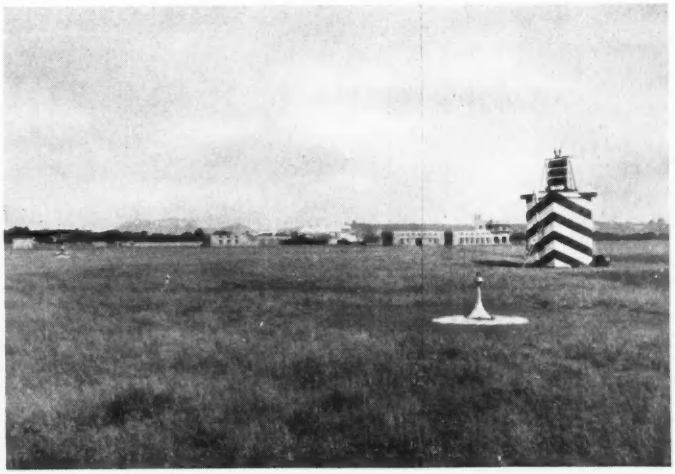


Fig. 8.—Floodlight on structure and cone boundary light at Jodhpur. The control building is in the background.

Later on, when the question arose of the shipment of material from this country, it was necessary in most cases that the large amount of miscellaneous gear required at any one aerodrome should be sent in one consignment, as it would obviously be uneconomic to send gangs of men to and fro over distances of several hundred miles, to the various aerodromes because some of the material was not on site. When it is realized that twelve different works of the G.E.C. alone were directly concerned with the manufacture of the equipment, it will be seen that elaborate transport arrangements, and internal co-operation between works was an essential part of the scheme.

Karachi.

Turning now to details of the actual installation, it will be seen from fig. 2 that Karachi is situated at the entrance of the air route to India, and branch air routes start thence to Lahore, Bombay and Madras. Karachi is probably the most important aerodrome in India from the point of view of traffic, and a very comprehensive lighting scheme has been installed.

The aerodrome is at Drigh Road, about seven miles from the city and nine miles from the Docks. All equipment had to be brought up by road and special arrangements made for obtaining local labour for cable laying, etc. The climate is humid, but

little rain falls, and the soil is full of saltpetre, making it necessary for all cables laid in the ground to have special protection.

Air traffic had to be maintained without interruption during the whole time the installation was being undertaken. (This applied to every other airport on the route). Cables which crossed the landing ground, had therefore to be laid in sections, one section being completed before the next was started.

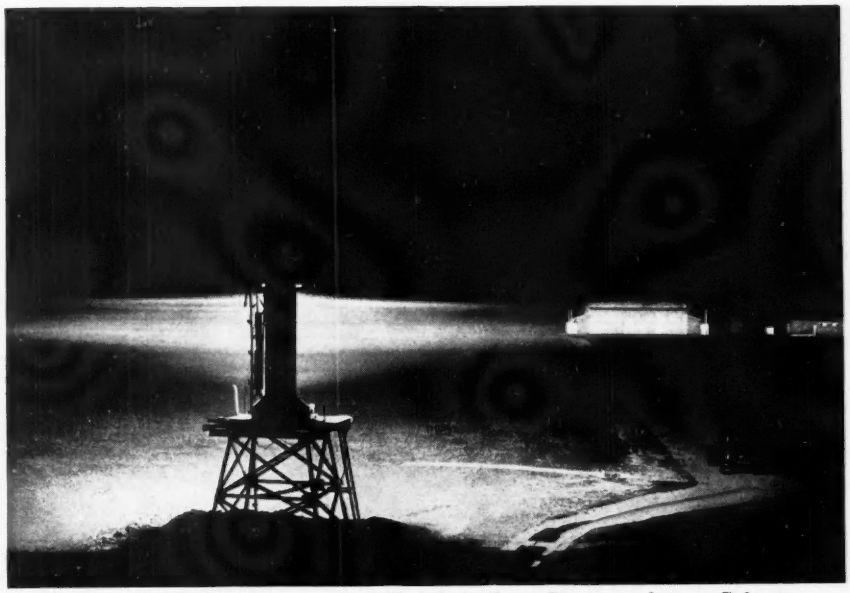


Fig. 9.—9 kW floodlight beacon installed at the Dum-Dum aerodrome, Calcutta.

Three 9 kW nine-lamp floodlights were installed so that aircraft could land in any direction without subjecting the pilot to glare. Each one of these floodlights illuminates practically the whole landing ground.

The available electricity supply was at 440 volts D.C., and as an A.C. supply was necessary for the boundary light system (in view of the great saving in cable effected by a 400/230 volt A.C. distribution more than outweighing the capital cost of installing twin motor alternator sets) the whole of the supply to the night landing equipment was converted to this A.C. system. The output of each of the sets is 20 kW and the set to be used is selected by means of a changeover switch in the intake room. Starting is effected by a push button in the control tower, which operates a solenoid operated multiple contact starting unit. The alternator panels are equipped with frequency meters and feed a contactor type switchboard for the outgoing circuits, which is also controlled from the desk in the control tower.

A route beacon is mounted on top of the airship hangar at a height of 280 feet.

Hyderabad.

The installation at Hyderabad (Sind) calls for no special comment as the aerodrome is only used as an emergency ground, and is therefore equipped only with a wind indicator, boundary lights and obstruction lights.

Uterlai.

Uterlai is situated in the desert, and great difficulty was experienced in obtaining local labour. The erection staff had to make special arrangements to obtain food and drinking water, and although a railway runs near the ground, there is only one train a day. While the installation of a small generating plant and cabling would normally have presented few difficulties, the same work carried out 300 miles from a town in a locality abounding in snakes and scorpions was beset with troubles, which were not in any way eased by the strange language of the local inhabitants.

Delhi.

No equipment was installed at the aerodrome at Badhal, and the next ground was therefore Delhi. An up-to-date control building and hangars are installed here, and a 3 kW neon beacon flashes the letter "D" from the summit of the control building. There is one unusual feature on this ground, namely,

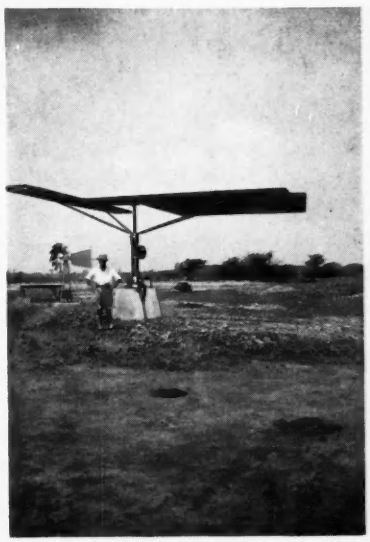


Fig. 10.—Wind tee and windmill at the Dum-Dum aerodrome, Calcutta.

the Saf-dar-jang tomb, a domed marble building 90 feet high. It was considered inadvisable to place an ordinary obstruction light on top of this, in view of the probability of offending local religious feeling. The dome is therefore illuminated in red by four "Osira" floodlights. This arrangement is not only pleasing in appearance but adequately defines the obstruction to aircraft.

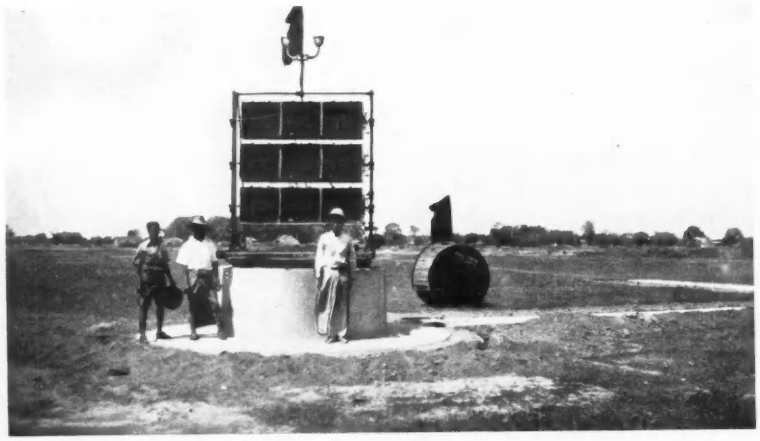


Fig. 11.—9 kW, 9-lamp landing floodlight at Akyab aerodrome.

Cawnpore and Allahabad.

As regards the aerodromes at Cawnpore and Allahabad, the former is to be further extended and improved so that a minimum of lighting has so far been installed, while that at Allahabad has three 9 kW nine-lamp floodlights and a $1\frac{1}{2}$ kW route beacon mounted on top of the hangar.

Gaya.

Gaya aerodrome—midway between Allahabad and Calcutta, has its own power station, and a 9 kW three-lamp floodlight beacon has been mounted on the flat roof (fig. 7). This unit which rotates at 12 r.p.m. can, by an ingenious method of tilting the reflectors, throw a beam of nearly $1\frac{1}{2}$ million candles at an angle up to 30° above the horizontal. When aircraft come in to land, the beam is depressed and illuminates the landing ground. In addition, there is a 9 kW nine-lamp floodlight for use when the wind is blowing in the other direction.

Calcutta.

At Dum-Dum Aerodrome, Calcutta, a 9 kW three-lamp floodlight beacon had already been installed (fig. 9). This has been connected up to the new switchboard, and a further $4\frac{1}{2}$ kW floodlight originally at Karachi, has also been installed here.

Akyab.

Akyab is on an island on the Burma coast, two days by boat from Rangoon. This proved to be one of the most difficult grounds to equip, owing to its inaccessibility, and to the excessive rainfall which exceeds 200 inches per year. Two floodlights are employed here (figs. 11 and 12), and runways are necessary for use during the monsoon.

Rangoon and Bombay.

The aerodromes at Rangoon and Bombay call for little comment, except that at Bombay, obstruction lights have been used on 120 foot towers to light a gap cut between palm trees fringing part of the ground Approaches and take-offs in this direction have to be made through this gap.

In conclusion it is of interest that apart from a few minor alterations which were made necessary later due to the extension of certain landing grounds, the whole of the material was manufactured, shipped and installed within eleven months.

Fig. 12.—9 kW, 3-lamp shadow bar floodlight at Akyab aerodrome.

Modern Receiving Valves: Design and Manufacture.

PART II.

By M. BENJAMIN, B.Sc., Ph.D., C. W. COSGROVE, B.Sc., A.M.I.E.E., and G. W. WARREN, B.Sc.

Research and Engineering Staffs of the M.O. Valve Co., Ltd., at the Works, Hammersmith, and G.E.C. Research Laboratories, Wembley, England.

This is the second and concluding part of an article which started in the August issue (Vol. VIII, No. 3) of the G.E.C. Journal; it is reprinted from the Journal of the Institution of Electrical Engineers, April, 1937. The authors deal in this section with cathodes, heaters, getters and the pumping and activation processes.

The main factors affecting the life of a valve are discussed and methods described of minimising some of the limitations of a valve such as hum, microphony and frequency limitation. The article concludes with some observations on possible future developments.

CATHODES.

ONE of the chief features of the modern receiving valve is the highly efficient oxide-coated cathode employed. It is proposed to discuss this type of cathode fully, but, before doing so, it is informative to review the various types of emitters that have, at various times, been used. In this way some of the difficulties of manufacture can also be considered.

Thermionic emitters can be divided into three groups: (*a*) Clean-metal emitters; (*b*) contaminated-metal emitters; (*c*) oxide emitters. The commercial development of each class of emitter followed the order given.

(a) Clean-metal Emitters: Tungsten.

The phenomenon of electron emission was first discovered in an electric lamp, and the thermionic valve was developed originally as an offshoot of the lamp. The desirable features in an emitter then, as now, were that it should possess reproducible thermionic characteristics, mechanical strength, and long life. Emission efficiency was not a very serious problem, since heating watts were not important, and the valve characteristics could be satisfied by employing multiple cathode systems. All the first valves were of the directly heated filament type, so that the cathodes consisted of a wire or series of wires. Tungsten, which was being used as a lamp filament, suited the requirements of the early valves very well. In order to obtain reproducible thermionic characteristics, it was essential that the metal surface should be free from gas and other impurities. Tungsten, because of its high melting-point (3,370° C.,) could be raised to high temperatures on the pump, and its surface could thus be thoroughly cleaned. It could be operated at a temperature sufficiently high to ensure freedom from contamination by gas. The operating temperature was such that, although the filament had ample emission, it had a sufficiently low rate of evaporation to give a long life. The vacuum treatment was simple. The valve was baked and the filament was then flashed close to the melting point of the metal. The electrodes were bombarded in order to outgas them, and the valve was sealed off.

(b) Contaminated-metal Emitters.

(i) *Thorium-on-tungsten.*

In order to improve the mechanical properties of the tungsten used for lamp filaments, thorium oxide was added to the tungsten oxide during the manufacture of the tungsten, about 0·7 per cent thoria being obtained in the final wire. Langmuir[21] showed that thoriated tungsten had a considerably higher thermionic emission than tungsten at the same temperature. Thorium, obtained by reduction of the thorium oxide, diffuses to the surface of the tungsten, and at temperatures where bulk thorium could not exist a monatomic layer adheres to the tungsten surface, with the result that its work function is reduced [22][23].

The treatment of the thoriated tungsten filament was generally as follows:—

The electrode system was outgassed on the pump by high-frequency treatment, and by bombardment from the filament run under ordinary tungsten conditions. The valve was then sealed off, and the filament flashed near the melting point for a minute or so. This treatment cleaned the wire surface, and at the same time reduced some of the thorium oxide to thorium. The filament was then run at 2,200° K. At this temperature thorium diffused to the surface,

(21) A reference is given at the end of this article for this and subsequent numbers.

and there formed the active layer. The operating temperature for these filaments was 1,900° K.

The thorium layer on the surface, being chemically very active, was easily "poisoned" by the presence of oxygen or water vapour. This danger could be avoided if the pumping time were prolonged. An alternative solution was to carbonize the filament. A small amount of a hydrocarbon vapour was admitted to the hot filament, and the hydrocarbon combined with the tungsten to form tungsten carbide. The usual method was to burn the filament in the vapour until its resistance had increased by 7 per cent. The thorium was produced by running the filament off the pump at 2,400°K. for several

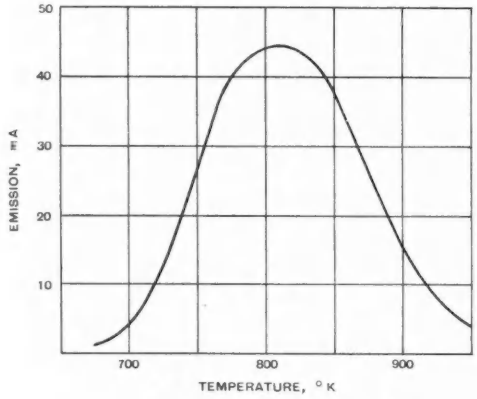


Fig. 30.—Emission from W-O-Cs.

minutes. The carbide produced thorium by its reducing action on the thoria. The filament was then run at 2,200° K. in order to stabilize the emission. Furthermore, the filament was protected against "poisoning" by the presence of the carbide, which was preferentially attacked by gas and water vapour. The gaseous products of the attack were adsorbed on the walls of the glass bulb.

The main objection to the carbonizing process was the fact that the filament was rendered very brittle by the carbide, and valve losses in transport were very heavy. The solution to this trouble was the stranded filament. It was made very much as a 7-strand cable is made, *i.e.*, six wires were twisted round a central wire of similar diameter. During carbonizing, only the exposed surfaces of each wire were carbonized, and the central wire remained unaffected. This filament was therefore much more robust.

The operating temperature for maximum efficiency is determined by the temperature necessary to maintain the optimum covering of thorium atoms, and this is too low to stop the cathode cleaning-up evolved gas. To counter this defect, a "getter," *i.e.*, a layer of some substance that will adsorb gas, is deposited on the inside of the glass envelope. The early getter was phosphorus, which was originally used in lamps for removal of water vapour. Later getters were alkali or alkaline-earth metals. The action of getters is discussed more fully later in the paper.

(ii) *Caesium-on-oxygen-on-tungsten* (*W-O-Cs*).

The discovery that the work function of a metal was reduced when a layer of atoms of another electropositive metal was present on its surface led to much work on this form of emitter [24] [25] [26] [27]. Generally, the more electropositive the contaminating metal is, the more the work function is reduced. A still greater reduction in work function is obtained when the contaminating film consists first of a layer of electronegative atoms such as oxygen, and then the layer of electropositive atoms. The most efficient form of this sandwich type of surface yet developed is caesium-on-oxygen-on-tungsten. The tungsten surface is prepared as follows: The tungsten is first oxidized. It is next heated in vacuum until only a monatomic film of oxygen remains, and caesium is then evaporated on the surface from a suitable source. The final cathode is again heated in vacuum at a suitable temperature in order to obtain the maximum activity.

Despite the high emission efficiency of this type of emitter, it has never been successfully developed commercially. The properties of caesium valves have been extensively studied in the G.E.C. Research Laboratories, and the following facts have been established. The emission varies with temperature as shown in fig. 30, and the operating temperature for maximum life is about 810°K. This low temperature is necessary because the degree of covering of the tungsten surface is a function of the vapour pressure of the caesium, and of the temperature of the cathode. The vapour pressure in turn is affected by the bulb temperature. The emission density is very low, so that an extremely large cathode area is necessary and microphonic problems in filamentary types become in consequence much more serious. The cathode can only be operated with very low anode voltage ($\not>$ 120 volts), because positive ions will readily remove the caesium atoms by a bombardment process. Judged from a manufacturing standpoint, a very high degree of skill is required to make this form of cathode, and it has so far proved unsatisfactory for commercial development.

(c) Oxide Emitters.

(i) *The alkaline-earth oxides.*

As early as 1904, Wehnelt[28] showed that the emission from a metal wire coated with calcium oxide was very high when compared with the emission from the metal itself. It was not until 1914, however, that this form of emitting cathode was used commercially by the Western Electric Co.

The demand for highly efficient cathodes which

were inexpensive to operate focussed commercial attention on the oxide emitters. A considerable improvement in the standard of high-vacuum technique had to be achieved, however, before general commercial manufacture could be contemplated. We have seen that, as the emitter becomes more efficient the degree of vacuum becomes increasingly important, because of the "poisoning" effect of gas on the emitter. The oxide cathodes are generally produced in the evacuated bulb, and a large quantity of gas has to be removed from the valve before any activation of the cathodes can be attempted. Two processes have been in general use. In Europe, the process was to plate a tungsten wire with a thin film of copper. The copper was oxidized, and the alkaline earth, usually barium, was obtained by decomposition of the alkaline-earth azide. The barium metal combined with the copper oxide to form barium oxide.

This process, the vapour process, was introduced by the Philips Lamp Co., of Holland. The process had one distinct advantage: the large quantities of barium liberated during the distillation acted as a very efficient getter, both on the pump and during life.

In America, the oxide was formed by coating a wire with a paste of the carbonate or hydroxide. This paste, when raised to a suitable temperature in a vacuum, decomposed to form the oxide. The gas evolved had to be pumped away, and getters were employed during pumping in order to maintain a high vacuum.

TABLE 4.

Emitter	Efficiency mA per watt	Emission density mA per cm.²	Operating temperature °K.	Work function volts
W	1 to 5	274	2 500	4.52
W-Th ..	20 to 25	3 000	1 900	2.77
W-O-Cs ..	700	126	810	0.7
BaO, CaO, SrO	150 to 250	250	1 040 to 1 100	0.95

The vapour process lost favour when the necessity for indirectly-heated cathode valves arose. The distillation of barium introduced leakage between electrodes, and this leakage resulted in very noisy valves. To-day practically all makers of receiving valves employ the paste oxide type of cathode.

Table 4 summarizes the properties of types of emitters mentioned, and gives the results obtained over a number of years in the organization with which the authors are associated.

(ii) *Mechanism of the emission.*

The theory generally accepted[22] is that the alkaline-earth oxide coating behaves as an electronic semi-conductor. It conducts because of the presence of the right kind of impurity atoms, in this case barium atoms. The barium atoms are produced from the oxide, and it is these barium atoms which supply the conducting electrons. These electrons are finally emitted into vacuum because of the presence of a monatomic film of barium on the surface of the oxide. If certain assumptions are made, it can be shown that the Richardson equation

$$I = A\theta^2 e^{-(\phi-\mu)/k\theta} \quad . \quad . \quad . \quad (8)$$

holds for these oxides. μ, the inner potential, is given by

$$\mu = \tfrac{1}{2}(W_1 + W_2) + k\theta \log \frac{aN_0^{\frac{1}{3}}}{(\beta\theta)^{\frac{3}{2}}} \quad . \quad . \quad (9$$

where W_1 and W_2 are energy levels in the oxide, a and β are constants, and N_0 is the number of barium atoms per cm.^{3}; so that the work function depends on the concentration of barium atoms.

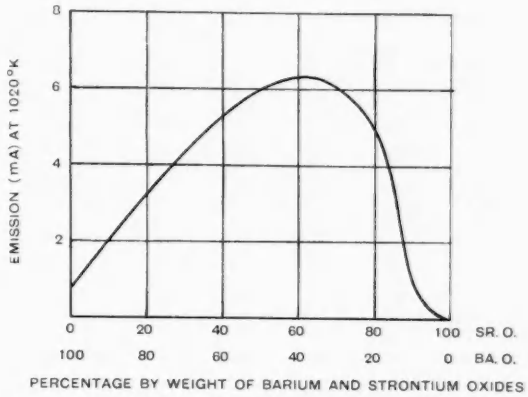


Fig. 31.—Emission from solid solution of barium and strontium oxides.

(iii) *Chemical composition and physical state of practical oxide coatings.*

The usual oxide coating consists of barium and strontium oxides present in equimolecular proportions or equal parts by weight. The oxides are usually obtained by decomposition of the carbonates in vacuum. It has been established that under ideal vacuum conditions, a mixture of the two oxides has a higher emission than either of the single oxides. The maximum emission is obtained when, for a given chemical composition, the oxides are present as a homogeneous solid solution. In fig. 31 the relation between emission and chemical composition of the double oxide is shown. The theoretical reasons for the necessity for the double oxide are discussed elsewhere[29] [30]. The emission also appears to be a function of the particle size of the double oxide. Thus, the three main features of the cathode coating are: (1) it should be a homogeneous solid solution of barium and strontium oxides. (2) It should have the correct oxide composition after final treatment in the valve. (3) The mixed oxide particles should be as small as possible.

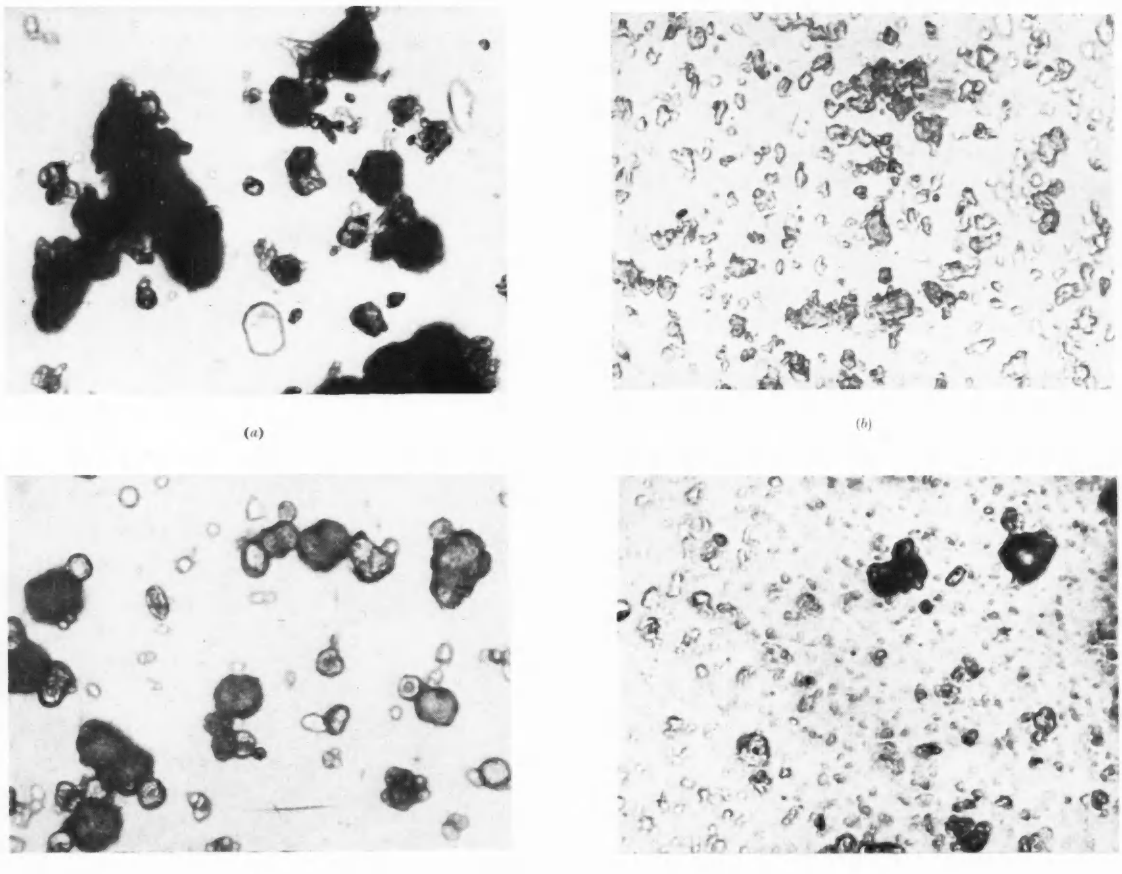
Condition (1) is achieved by correct preparation of the original carbonates. If the carbonates are in

solid solution, then they invariably give a double oxide when decomposed in a vacuum. The double carbonate is obtained by simultaneous precipitation from a hot alkaline solution of the nitrates.

Condition (2) is achieved by using the correct amount of each nitrate, and by ensuring that the nitrates solution is alkaline. Otherwise preferential precipitation of the strontium carbonate occurs, and the resulting carbonate may have two or more phases of varying chemical composition. On heating the double carbonates in vacuum, the temperature must be controlled, or else a change in chemical composition of the resulting oxide may occur. This point will be amplified under the heading "Pumping Technique."

Condition (3) depends on the way in which the precipitation from the nitrates solution is carried out. The exact nature of the precipitating agent, the alkaline agent used, temperature, speed of precipitation, and the solution strengths employed, are all important factors. Although there is not space to describe the various methods, the photomicrographs in fig. 32 illustrate the range of particle sizes that can be obtained. Recently, E. Patai and Z. Tomaschek[31] have described a method for obtaining carbonate particles of colloidal dimensions.

The authors are now studying the effects of the carbonate particle size by means of the electron microscope. Although the results obtained are not yet conclusive, it may be of interest to show just how two coated surfaces which differ only in the particle sizes of the original carbonates exhibit very different emission characteristics. In fig. 33 are shown the electron photomicrographs of two cathodes, one coated with the coarse-particle double carbonate and the other with the fine-particle double carbonate shown in fig. 32. It will be seen that while the emission density is very much the same for both, the total emitting area is very much greater in the case of the fine-particle carbonate. The photographs



(*a*) Precipitation using $NH_4OH + (NH_4)_2CO_3$.
(*b*) Precipitation using Na_2CO_3.
(*c*) Precipitation using $CO_2 + NH_4OH$.
(*d*) Precipitation using $CO_2 + NaOH$.

Fig. 32.—Effect of method of precipitation on particle size of double carbonate. (Magnification 1,000).

are reproduced here so that the importance of particle size can be visually appreciated.

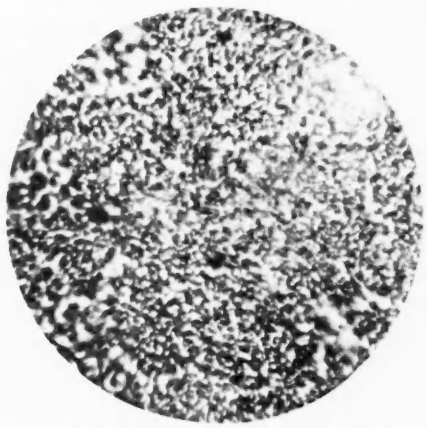
(iv) *The core material.*

The essential features of the core material are that it shall be mechanically strong, easily worked, have a high melting-point and low thermal emissivity, and be inexpensive.

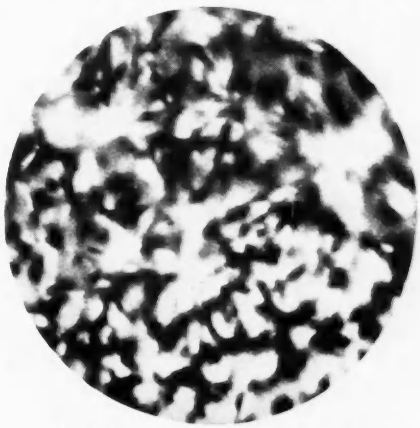
Nickel, copper, silver, gold, platinum, and various alloys of these metals are all possible core materials. Tungsten cannot be used, because shaped indirectly-heated cathodes are extremely difficult to make. Platinum and gold are too expensive, and silver is too volatile. Therefore, nickel or copper, both of which are cheap, might be used. Copper has one advantage over nickel; its thermal emissivity is much lower, and since, in practice, the temperature of the coated cathode is dependent on the thermal emissivity of the core and the thickness of coating, a coated copper cathode will require less power to maintain it at a given temperature than a similarly coated nickel cathode.

Curves showing the temperatures of coated copper and coated nickel at the same watts input per cm^2 are given in fig. 34. It will be seen that the temperature of the coated cathode depends on the coating thickness, and that at a given temperature a copper cathode requires about 25 per cent less power than a nickel cathode.

The chief disadvantages of copper are: (1) Its lower melting-point (1,080° C., as against 1,450° C. for nickel). (2) Its greater volatility (evaporation takes place at temperatures as low as 730°C.). It is therefore necessary to activate a copper cathode at a lower temperature than that employed for nickel (1,100° C.), and to operate the cathode at a maximum temperature of 730° C. At higher temperatures, any evaporation which takes place will give rise to electrical leaks and noisy valves. For these reasons, nickel is to be preferred as a core material, and it is the core metal normally used by all valve makers.

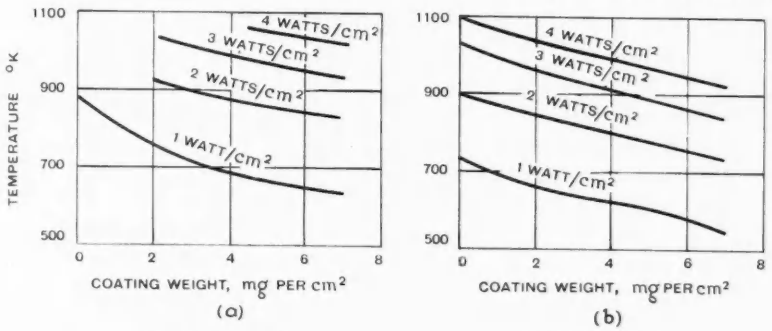


(a) Carbonate coating shown in fig. 32(*a*).



(b) Carbonate coating shown in fig. 32(*b*).

Fig. 33.—Electron-microscope photographs. (Magnification 200).



(a) Copper cathode. (b) Nickel cathode.

Fig. 34.—Effect of coating weight on temperature of coated copper and nickel cathodes.

It has been shown[32] that, in order to obtain the best thermionic results, certain metallic impurities, which will act as reducing agents to the oxide coating, are desirable in the nickel. These impurities increase the barium concentration by their reducing action, and so assist in improving the thermionic emission. Suitable metals are aluminium, magnesium, titanium, the rare-earth metals, and silicon. The actual amount and nature of impurity added is governed by the ease of manufacture of the nickel alloy, and by the following considerations: (1) Effect on thermal emissivity of the nickel (generally increased). (2) Effect on electrical resistance of the nickel (generally increased). (3) Effect on mechanical strength on the nickel (generally increased).

In the case of indirectly-heated cathodes (1) is the chief consideration. For directly-heated cathodes, some adjustment can be made to diameter and length which will offset the effects of (1) and (2).

In practice, the authors have found that, for directly-heated filaments, a nickel +2 per cent aluminium alloy is satisfactory. For indirectly-heated cathodes, the presence of up to 0·1 per cent of magnesium is best.

Attempts have been made to introduce barium directly into the core. Alloys of nickel and barium

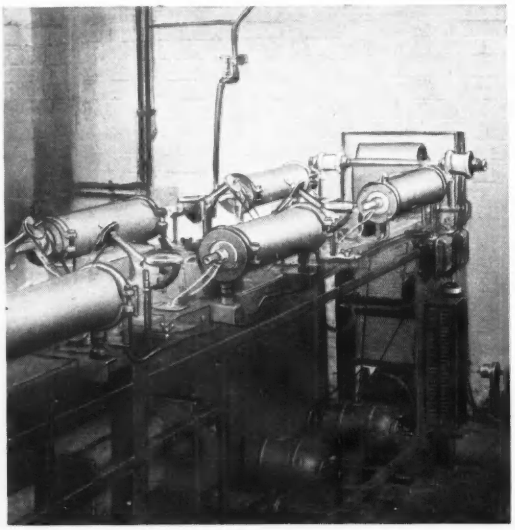


Fig. 35.—Filament-coating plant.

which contain more than a trace of barium are extremely difficult to make, and nickel-barium alloy cathodes have not yet been used commercially.

(v) *Coating processes.*

For directly-heated cathodes, in the form of a wire or strip the cathodes are made by drawing the wire through a series of baths and ovens. The apparatus is illustrated in fig. 35. The baths contain a water suspension of the carbonates together with about 12 per cent of barium or strontium nitrate, which acts as a binder. After passing through a bath, the wire passes through the oven at 750° C. The atmosphere is generally one of CO_2 in order to avoid any decomposition of the carbonates, and the authors have found that oxidation of the core due to nitrate decomposition can be avoided by the use of suitable mixed gases. This is important, as core oxidation slows up the cathode activation. In the oven the coating is sintered on (the nitrates decompose to form carbonates) and the final coating consists of a homogeneous double carbonate. This coating and sintering process is repeated until the required weight of coating is obtained.

For indirectly-heated cathodes, a suspension of carbonates in an organic solvent is made and sprayed on to the nickel base. The degree of adhesion of the coating to the core metal is governed by the nature of the diluent used and by the actual spraying conditions. The following factors are also important —stable viscosity of the spraying suspension, temperature of spraying, fineness of the carbonate particles.

The carbonates are decomposed to oxides by heating them on the pump. The carbonates begin to decompose at 750° C. An important factor in manufacture is that the time of decomposition should be kept as short as possible. In order to avoid evaporation of the coating, however, the temperature of the coated cathode must never exceed 1,100° C.

An additional complication is that the thermal emissivity of the coating falls when it changes from carbonates to oxides, so that a rise in temperature occurs although the watts supplied remain the same. A curve showing temperature-changes and time of decomposition of the carbonates is given in fig. 36.

HEATERS.

(a) Core Material.

In indirectly-heated types, the cathode is normally a hollow tube of circular, oval, or rectangular section, which is heated by means of a filament inside the cathode, but insulated from it. The core material is generally tungsten. Since the heater wire normally runs at a temperature several hundred degrees above that of the cathode surface, it is essential that

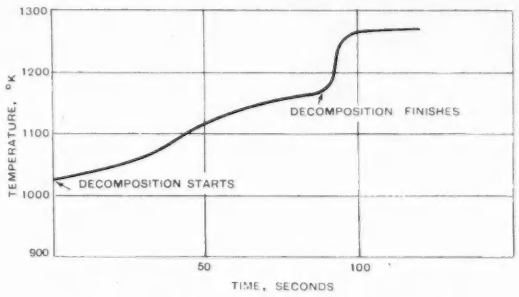


Fig. 36.—Cathode temperature-changes during degassing at 5.9 watts per cm.².

the wire should have a high melting-point. One of the disadvantages of tungsten, however, is that it is prone to brittleness at high temperatures. The brittleness, caused by crystal growth, can be avoided if 0·02 per cent alumina is added to the tungsten. This prevents temperature recrystallization below 2,000°C.

Another form of core wire now being used consists of a molybdenum-tungsten alloy. This alloy was first introduced in America, and the advantages are that the alloy retains the ductility associated with the molybdenum, and yet has a melting-point well above that of molybdenum, and a vapour pressure which is negligible below 1,750°C.

(b) Insulating Material.

The insulating material consists of a refractory

such as alumina which is sprayed on to the heater. The heater-cathode insulation, which must be as high as possible for circuit reasons, depends on: (1) The temperature of the heater. (2) The nature of the insulator used.

(1) A curve, showing variation in the heater-cathode insulation with temperature, for alumina-coated tungsten, is shown in fig. 37. It is essential to design the heater to run at as low a temperature as is possible.

(2) The current/voltage curve for a typical alumina coating is shown in fig. 38. It will be seen that a higher current flows when the cathode is positive with respect to the heater, and that it saturates. There is reason to believe that the alumina behaves as an impurity semi-conductor, although it is difficult to determine whether the leakage current is carried mainly electronically or electrolytically. There appears to be no doubt, however, that the purer the alumina the higher the insulation. The chief impurity in alumina is sodium, present as sodium aluminate, and this must be removed as far as possible by chemical means. The following treatments are usually given to the alumina:—

(i) As much alkali as possible is removed by prolonged acid washing. Generally the alkali can be reduced to 0·02 per cent. It is essential to store the washed alumina so that atmospheric contamination is reduced to a minimum.

(ii) After spraying, the coated heater is heated in hydrogen at a high temperature. This removes the binder, sinters the coating, and removes a certain amount of sodium and other impurities. Sometimes it is necessary to sinter the washed alumina in hydrogen at 1,600° C. before it is used for spraying purposes.

One other method of improving the insulation has been found to be effective. If a small amount (1–2 per cent) of beryllia is added to the alumina, the insulation is improved to a level reached by taking the precautions described above. It appears that the beryllia combines with the alumina to form a compound of the type $(BeO)_x(Al_2O_3)_y$. Its exact formula has not been established, but it is not the ordinary beryllium aluminate. It may be that in this compound the different cyrstals produced may have different energy levels, which result in the altered conductivity.

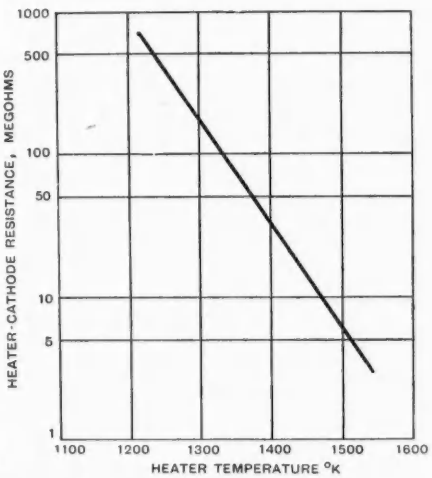


Fig. 37.—Electrical resistance of alumina coating.

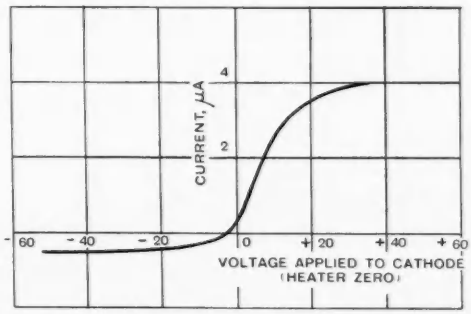
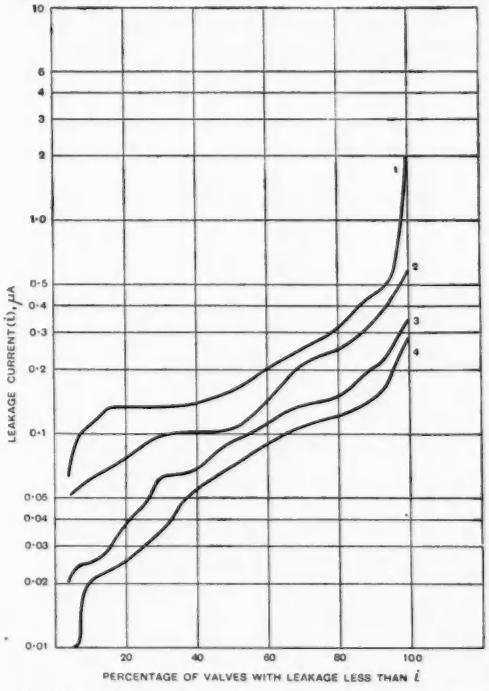


Fig. 38.—Current/voltage characteristics of alumina coating.

The effect of these treatments on the insulation is shown in fig. 39. It is a remarkable fact that at the operating temperature of the heater (1,400°K.), heater-cathode resistances of 80 megohms or more can be obtained.

One other feature leading to poor insulation is contamination by handling during assembly. It is



Curve 1. Alumina.
Curve 2. Washed alumina.
Curve 3. Alumina presintered at 750°C.
Curve 4. Aluminia + 1 per cent BeO.

Fig. 39.—Insulation distribution curves.

not always possible to avoid this, and the remedy is to apply a potential between heater and cathode during ageing. A "poisoning" of the conductivity occurs, and the insulation improves. The improvement is permanent, but the reason is not clear. The effect is shown in fig. 40.

Magnesia has been used as an insulating coating, but the authors have found it to be unsatisfactory. It can be readily obtained pure, but it cannot be sintered in the presence of tungsten without some combination occurring. Further, at 1,700° C. magnesia has an appreciable vapour pressure, so that coating may be lost during sintering, and during pumping. In the valve, the heater lighting treatment results in further reaction between the magnesia and the tungsten core, and a compound of the tungsten class is formed. The electrical characteristics of a magnesia-coated tungsten wire are extremely interesting, and are shown in fig. 41. It will be observed that initially the greater current flows when the cathode is negative with respect to the heater, but prolonged running with the voltage applied so that the cathode is positive (the normal condition) results in electrolysis of the coating, and tungsten is deposited on the coating surface adjacent to the cathode. A short-circuit results, and the heater fails. The objections to magnesia coatings apply to magnesia tubes, which have been used by valve makers to sleeve tungsten heaters.

(c) Heater-cathode Design.

In indirectly-heated valves the design of the combined heater-cathode system is important, judged from the standpoint of emission efficiency. For a cathode of a given area, dissipating a given number of watts, it is desirable that the energy should be

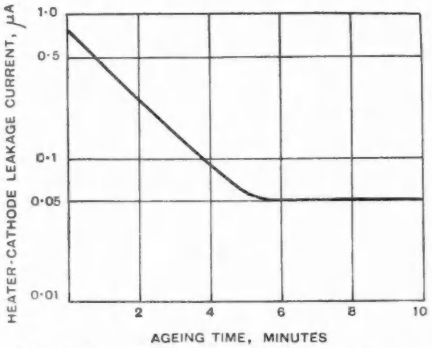


Fig. 40.—Effect of ageing with + 45 volts applied to cathode, for alumina coating.

distributed as evenly as possible over the cathode surface. With the ordinary hairpin type of filament, the temperature-difference between the end and centre of the cathode may be as high as 80 deg. C. This can be brought down as low as 5–10 deg. C. by suitable heater design.

The operating temperature of the heater is decided largely by the disposition of the heater in the cathode, for the latter is heated mainly by radiation (any conduction can only take place at a number of points or live contacts). It follows, therefore, that the lowest temperature of a heater which is dissipating a given number of watts, will be obtained when the radiating area of the heater is the greatest.

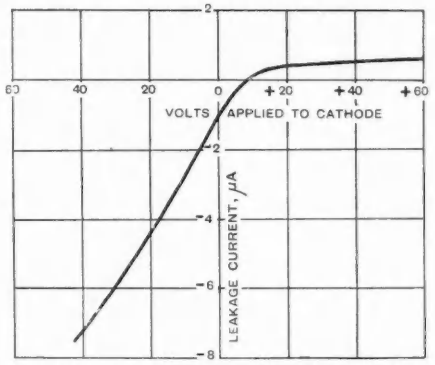


Fig. 41.—Current/voltage characteristic of magnesia coating

Thus, the most efficient heater would be a close-fitting cylinder. The nearest approach to this is a single helix wound with turns as close together as is possible.

In fig. 42 are some interesting curves for temperature distribution along the cathode, when various shapes of heaters are used. It must be borne in mind that heater design is influenced by such factors as magnetic-hum effects and coating problems so that it may not always be possible to use the lowest-temperature heater. One other disadvantage of low-temperature heaters is their greater heating-up time due to their larger thermal capacities and smaller differences between their cold and hot resistances. In Table 5, characteristics of a cathode with three different heaters are given.

"GETTERS."

A getter is used for maintaining the vacuum in a valve after it has been sealed off. The alkaline earths, the alkali metals, and magnesium, are common getters; and the getters mostly used to-day are an

TABLE 5.

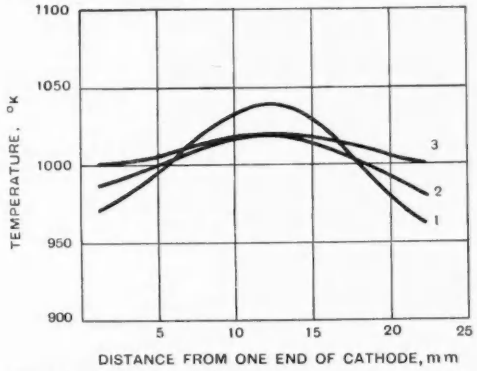
Heater	Heating-up time of cathode sec.	Temp.-diff. between centre and ends of cathode °C.	Operating temperature of heater °K.
Hairpin	11.2	80	1 460
Double helix	15.0	40	1 400
Single helix	17.9	10	1 360

alloy of barium and magnesium, and barium. The alkaline-earth oxides, singly or mixed, are also good getters.

(a) Method of Use.

(i) *Metal getters.*

If the metal is relatively stable in air, it is welded to a metal disc and dispersed by high-frequency heating of the disc. If the metal of which the getter is composed is an unstable one such as barium, it is packed inside a closed container before welding. The high vapour pressure generated on heating is sufficient to burst open the closed ends of the container, and the metal is dispersed. In order to avoid any deposits forming over the electrode bonding system and so causing electrical leaks, the getter dispersal is usually directed towards the bulb wall by a suitable design of container.



Curve 1. Single hairpin heater.
Curve 2. Reverse helix heater.
Curve 3. Single coil heater with centre return lead.

Fig. 42.

(ii) *Non-metallic getters.*

Where very high inter-electrode insulations are required, as in certain special types, the non-dispersed form of alkaline-earth oxide getter is used. This is usually sprayed on to a metal disc in the form of cathode coating, and decomposed by high-frequency heating to the oxides. The oxides when cold, act as getters. Although the authors believe this to be the first time that the oxides have been used in this way, for many years some valve manufactures applied a paint of alkaline-earth carbonates to the pinch.

It will be appreciated that since the emitting cathode itself is a mixture of alkaline-earth oxides, it too, in the active state will adsorb gas, and this point must be carefully watched when valves are being made.

(b) Mechanism of Clean-up.

The gettering action of dispersed metals is two-fold[33]. During dispersal a clean-up occurs, referred to as "volume gettering." Then when the gas comes into contact with the dispersed getter deposit a second gettering action occurs, known as "contact gettering." The gas is taken up either because it is adsorbed into the metal, or because it combines chemically with the metal. The actual nature of the clean-up depends on the type of getter, the nature of the gas, and the conditions prevailing at the time. For example, magnesium will adsorb hydrogen in contact with it, and this can be liberated again by heating the magnesium deposit. It will not adsorb CO_2, except under discharge conditions. Sodium will not getter hydrogen except under discharge conditions, and then it chemically combines with it to form the hydride. Barium will adsorb all the permanent gases, and it forms chemical compounds with oxygen and hydrogen. Hence barium is the most desirable getter, because of its affinity for most gases, and because the chemical nature of the clean-up means that the gas will be held even when the getter surface is hot.

The alkaline-earth getters clean up by an adsorption process and are most efficient when dealing with CO_2. The gas is easily liberated on warming or by electron bombardment.

(c) Precautions in Use.

Since getters may liberate adsorbed gas when warm, they should be deposited on the coolest part of the system. Direct electron bombardment may also liberate gas, and care should be taken to put the deposit in such a position that it is unlikely to acquire a positive potential. If possible, the getter deposit should be at cathode potential. In any case, since the metal disc always contains some getter residue, it is desirable to connect it to the cathode.

Fig. 43.—Screened output pentode.

PUMPING TECHNIQUE.

The pumping of a modern receiving valve is designed to remove the greatest amount of gas in the shortest possible time. All the materials used are rendered as gasfree as possible before assembly (see section on "Properties of Materials"), and the com-

pleted valve is heated on the pump to remove any remaining gas. In fig. 43 a complete valve assembly of a power output (type N43) valve, including the heater, cathode, multiple electrode system, and getter, is shown. The pumping system used consists of a series of 2-stage machine pumps. Figs. 44A and 44B respectively show photographs of a pumping unit and a battery of pumps. The speed of pumping

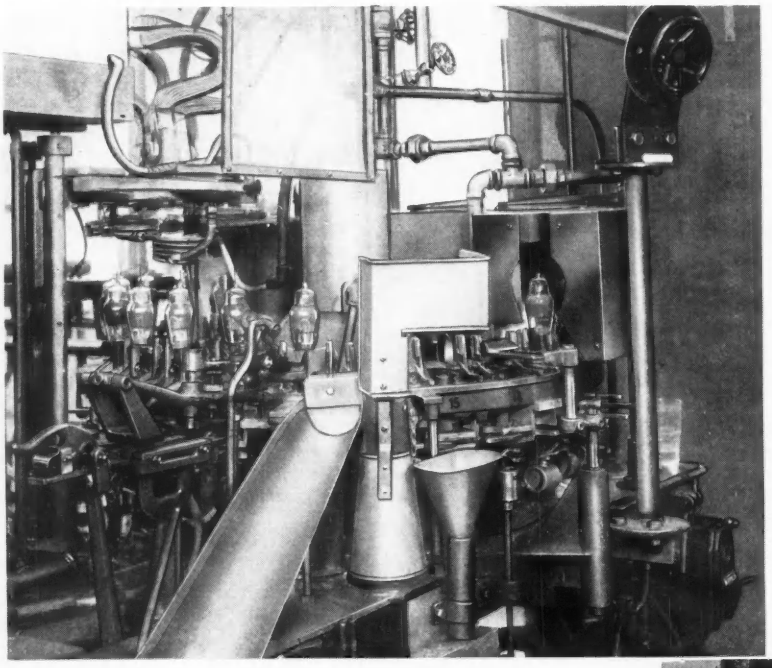


Fig. 44a.—Pumping unit.

is given in fig. 45.

The pumping procedure is as follows: (*a*) The system is baked at 450°C. in order to remove water vapour. (*b*) The electrode system is heated by high-frequency induction in order to remove adsorbed gas. (*c*) The cathode is heated in order to decompose the carbonates, the electrode system again being heated to prevent it picking up cathode gas. (*d*) The getter is dispersed, and the valve sealed off. The time taken to treat an individual valve varies according to type, but a speed of 400 valves an hour is an average figure when using a unit of the type shown.

The precautions to be observed are as follows: (i) the electrode system should be heated in such a manner as to ensure that excessive peaks of gas pressure are avoided. (ii) The cathode temperature should be maintained throughout the pumping process, since once the carbonates are decomposed the cathode is in an active state, and, as has already been pointed out, it will adsorb gas at low temperatures. (iii) The getter should be dispersed when the pressure is low, so that it is not employed in cleaning-up gas from the pump system. For this reason, the valve should be sealed off as soon as the pump has had time to remove any gas liberated by the gettering operation.

ACTIVATION PROCESS.

The process of keeping the cathode hot after decomposition results in partial activation of the cathode. Activation is completed by drawing current from the cathode whilst it is run at a temperature of 900° C. The electrolytic process going on in the coating results in the formation of more barium, and the space current grows with time. Further, the voltage across the valve and the current flowing ionize any gas present, and enables the getter to clean it up. The time and nature of the activation depend on the specific type, but as a general rule the cathode is run at 850°–900°C. with all other electrodes strapped at a common positive potential, and a space current of 100 mA per cm^2 is drawn for 2–5 minutes. The valve is then run for 30 minutes under normal operating conditions, except that the cathode temperature is still maintained at 850°–900°C.

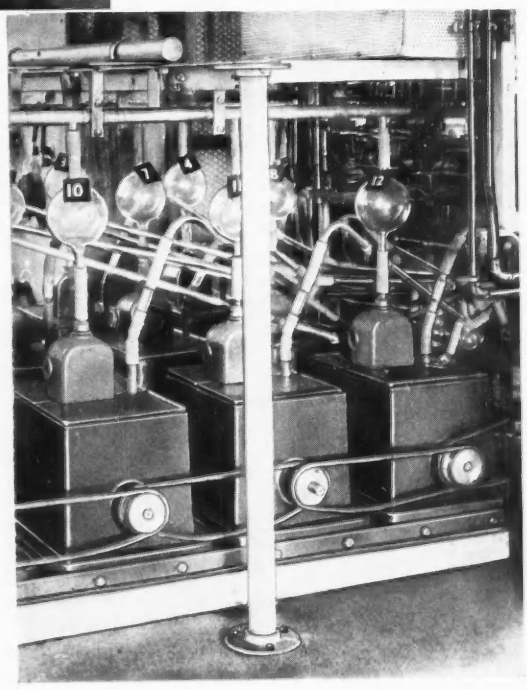


Fig. 44b.—Battery of pumps.

The initial bombardment period cleans the first grid surface, and any barium deposited from the cathode during the second period comes down on to a clean surface. This is important, particularly in high-μ types. The contact potential between grid and cathode determines the voltage at which grid current starts, and the activation schedule outlined above enables some measure of control to be exercised over the contact potential.

VALVE LIFE.

(a) Emission Life.

The life of the finished valve depends on the temperature of the cathode, and its resistance to poisoning by evolved gas.

As is shown in fig. 31, the emission from the solid solution of oxides is a function of the proportions of each oxide present. The oxides evaporate, and the barium oxide is considerably more volatile than the strontium oxide. Thus if the coating is run at such a temperature that appreciable volatilization of BaO occurs, the composition of the solid solution changes and the emission slowly falls. The rate of fall decreases with time, because the rate of evaporation of BaO decreases with increasing strontium content. The lowest possible temperature consistent with the emission demand will give the longest life, providing any poisoning effects are absent.

The oxide cathode usually fails because it adsorbs gas and is "poisoned." One of the factors which contribute to poisoning is the gas evolved from the electrode system because of the energy dissipated. As has been shown, the cathode readily adsorbs gas, and the lower the temperature of the cathode the more readily is the gas adsorbed. The getter is present in order to cope with evolved gas, but its capacity is limited, and the valve needs only a very little of a gas such as oxygen or carbon monoxide, both of which are readily adsorbed by the cathode coating, to poison the emission. Poisoning occurs at pressures of oxygen as low as 10^{-6} mm. of mercury, and recovery is generally impossible.

The cathode ceases to adsorb gas at about 1,000°C. but this temperature is too high from the point of view of coating evaporation. In actual practice, the cathode temperature must be adjusted to suit the type of valve. Where very little emission is required, as in a high-μ triode, and where few watts are dissipated in the anode, the operating temperature can be as low as 750°C.; but for a rectifier which requires a large emission throughout life, and in which considerable watts are developed, the temperature during life must be not less than 850°C.

One other factor influences life. The design of the heater-cathode system determines the temperature distribution along the cathode. If the temperature-difference between end and centre is great, then the ends will become poisoned, and the valve will fail because part of the cathode has been rendered useless.

(b) Mechanical Life.

Apart from failure of the emission, the valve may fail because it develops a mechanical defect. One such form of failure is for the heater of an indirectly heated valve to fracture, particularly when it is of the hair-pin type. This is usually due to the fact that the tungsten expands and contracts much more rapidly, when the heater temperature is varied, than the insulator coating, which adheres tightly to it. The condition is particularly severe when the valve, as in practice, is switched on and off several times a day. To avoid this difficulty it is desirable for the coating, instead of forming a smooth shell, to consist rather of a series of beads. The difference in appearance is shown in fig. 46. The effect is obtained by careful control of the initial density of the insulating material, so that the coating on the heater can shrink during sintering.

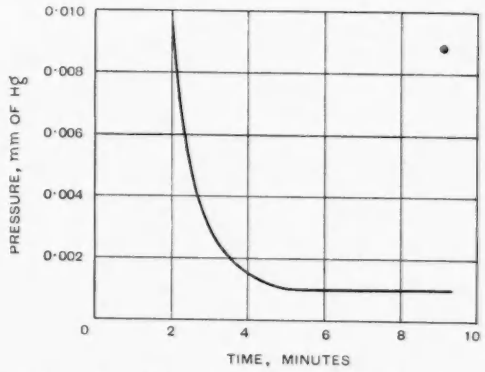


Fig. 45.—Pumping speed of a machine pump.

(c) Electrical Life.

Other causes of failure are the development of electrical leaks, grid emission, and gas in the valve during life. No specific cure for any of these troubles can be listed, but any particular type must be treated according to the symptoms observed.

Electrical leakage may be due to volatilization of active cathode material and getter, and designs must be modified to overcome these defects. Grid emission must be looked after by suitable design of the grid cooling arrangements which have already been described. The evolution of gas during life must be studied from the point of view of the gas content of electrode materials, the pumping, and the gettering techniques. All these factors are dealt with in detail in various sections of the paper.

Where very long lives (20,000 hours and more) are required, as in valves for use in P.O. telephone repeater circuits, low-temperature operation of the

cathode is essential. In order to avoid poisoning during life, the pumping schedules are lengthened to an extent quite impracticable for ordinary manufacture of valves for broadcast reception. The lengthened pumping treatments are necessary in order to ensure that practically no gas is evolved in the valve during subsequent operation.

LIMITATIONS DUE TO BACKGROUND NOISE.

Since the main function of a receiving valve is

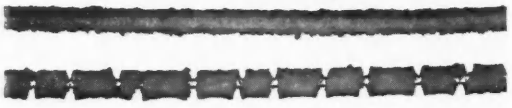


Fig. 46.

to amplify signals it follows that any noise generated by the valve itself will set a limit to the maximum useful gain which can be employed.

In the early days of bright-emitter valves a phenomenon known as "crackling" was often met with. This was an intermittent effect which was ascribed to irregular emission from the hot tungsten filament. With the introduction of thoriated tungsten dull-emitter valves the filament became less ductile and was more easily excited by mechanical shock into a state of transverse vibration. In consequence the limit of amplification at that time was determined mainly by the microphonic properties of the valve.

(a) Alternating-current Hum.

When the need for the operation of receiving-valve cathodes from an alternating current supply arose, a fresh limitation presented itself in the form of a.c. hum. Early attempts to use valves with a.c. heating of a filamentary cathode met with considerable difficulty. The first modifications were heavy-current low-voltage filaments, which avoided flicker due to temperature-changes and reduced the electrostatic control of the electron stream. Unfortunately, the heavy current produced a strong magnetic field, which set a limit to this method. Nevertheless, commercial receivers were manufactured for a time on these lines.

The functions of heater and cathode were now separated, so that the current did not flow through the cathode material. Difficulties arose due to the need for providing insulating material between heater and cathode. Vacuum insulation was of course satisfactory but required liberal dimensions, which resulted in high-consumption heaters and inefficient valves from the mutual-conductance point of view. The development of special insulating materials has been dealt with elsewhere in this paper, and it will be sufficient now to indicate the present limitations of indirectly-heated-cathode valves.

Where the heater can be operated with cathode return to the centre point of the heater supply, the main source of hum is magnetic in origin. The effect can therefore be reduced by reducing the heater current and to some extent by special arrangements of the heater. Assuming the heater watts to remain constant, the low-current method results in increased heater voltage with a greater increase in the hum produced when the slider of the potentiometer shunting the heater is moved from the centre point. This is due to: (1) Heater ends producing a grid effect on the electrons from the end of the system. (2) Thermionic emission from the heater being collected by the grid (especially with high resistance in grid circuit). (3) Ends of heater robbing electrons from the main system, either at the ends or strays. (4) Capacitive coupling between heater leads and grid lead.

These effects are set forth quantitatively in fig. 47. The curve for the MH4 valve shows the hum produced by the straight "hairpin" heater operated at 4 volts, 1·0 amp. Contrasted with these is an MH41 valve fitted with a heater of spiral or reverse "helix" form. The difference in hum at the ends of the potentiometer is a feature of the electrode arrangement, but the reduction in magnetic hum at the centre point is marked. The third pair, for the H30 valve, concerns a further heater of spiral form but operating at 13 volts, 0·3 amp. Here the magnetic hum at the centre is still further reduced by the lower current, and the steep rise at the end has been minimized by taking the grid connections to the top of the bulb and by the use of screens round the heater leads.

A special case of commercial importance arose with the introduction of the D.C./A.C. set, where for the sake of economy the heaters are operated in series on an A.C. supply. It is necessary for the cathodes of all the valves to be connected to one end of the A.C. supply, so that large A.C. voltages exist between the heater and cathode in many of the valves. In this case the A.C. voltage between heater and cathode may be several times as great as the voltage across one heater. All these effects can be minimized by enclosing the ends of the heater in metallic shields connected to the cathode and by removing the grid lead as far away as possible from the heater leads.

In general, it can be said that it is now possible to make valves, which, when operated on an A.C. heater supply, will give rise to a hum no greater than the basic "hiss" level arising from the shot and resistance noises. Such valves, however, demand special construction and are more expensive to manufacture than ordinary types.

While these latter effects are now well known as

limitations to the amplification obtainable with valves, it is proposed to refer to them briefly.

(b) Shot Noise.

The noise due to this effect arises from the random nature of the arrival of electrons as discrete particles at the surface of the anode. They generate a wide band of frequencies, and have been shown by Moullin and Ellis[34] to be equivalent to a mean-square voltage of approximately $11 \times 10^{-20} Idf/g_m^2$ at the grid of the valve in the case of an amplifier covering the range of audio frequencies given by df, where I = anode current (amperes) and g_m = mutual conductance (amperes per volt).

(c) Resistance Noises.

In most applications of the valve it is necessary to connect a high resistance or impedance in the grid circuit. This resistance gives rise to further noises, which again cover a wide frequency band. Johnson and Nyquist[35] [36] have shown that the effect of these is equivalent to a mean-square voltage of $1{\cdot}6 \times 10^{-20} Rdf$ across the resistance when the latter is measured in ohms.*

A practical case where noises of this kind prove a serious limitation is in the application of the photo-electric cell, where a high grid resistance is imperative owing to the low currents produced by the cell. In this field the electron multiplier, described by Dr. V. K. Zworykin[39] is of particular interest. By dispensing with the need for a coupling circuit the resistance noises are eliminated, and the limiting noise becomes of the smaller order arising from shot noise due to the multiplier.

(d) Parasitic Noises.

Apart from these fundamental limitations designers are faced with more immediate problems by reason of noises of a greater magnitude which can be classed as "parasitic." In the manufacture of modern oxide-coated cathode valves it is necessary to heat the electrodes, including the cathode and heater, to high temperatures during evacuation. It is also essential to employ some form of "getter," usually in the form of a volatilized film to assist in removing occluded gases. These operations may result in the evaporation of the electrode metals, which tend to form conductive films on the materials used to support and insulate the electrodes. The cathode also will release barium metal during pumping and activation. These films may give rise to high-resistance leaks of variable effect due to the bad contacts between them and the electrode supports. Various types of "umbrella" insulators have been employed with success to obviate these effects, while careful attention to pumping technique may also yield beneficial results.

Again, it is found that noise may arise as the result of ionization in the valve. At quite low pressures, of the order of 10^{-5} mm. of mercury, these noises may easily exceed those produced by the shot and thermal effects, if a high grid resistance is used. They are, of course, of a similar nature, but are set up by the positive ions resulting from the ionization of the gas.

In the manufacture of modern receiving valves having a large number of grid electrodes with very small inter-electrode spacing, the problem of excluding foreign material is a very real one. A considerable quantity of dust and fluff is normally present in the air and this may settle on the electrodes during assembly and be sealed in with the system.

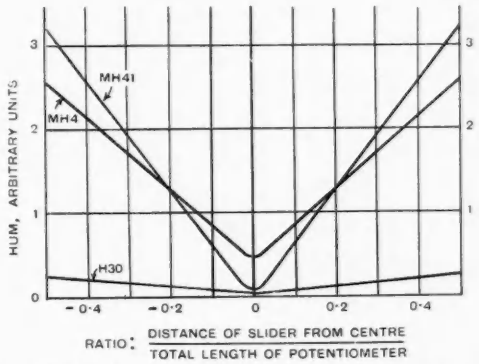


Fig. 47.—Effect on hum of various heater-cathode designs.

During heat treatment much of this material will be carbonized and provide loose-contact short circuits in the final valve. It will be appreciated that only one fragment of suitable shape is necessary in a valve to render it useless for normal purposes. Elaborate precautions have been found to be necessary to exclude this material.

Another parasitic effect with which all users of valves will be familiar is that of microphonic noise. This of course arises from movements of the electrodes relative to one another, resulting in slight changes in the characteristics.

In filament (battery) valves the main source of the effect is the transverse vibration of the filament wire or strip. Much has been done to limit this vibration by the use of insulated members to contact with the filament at intermediate points and so produce a damping action. Each contact of this kind, however, robs the filament of some of its heat and so limits the number which can be used. Moreover, owing to the small clearances used in modern battery valves, the insulating path is necessarily short and the difficulties of avoiding noise due to films are considerably increased.

* For a complete bibliography on valve noise, see Reference (38).

In indirectly-heated valves the cathode is a comparatively rigid structure, and if the electrodes are well bonded at the two extremities a much lower level of microphonic response is possible than in the case of battery valves. If the gain now be increased it will be found that microphonic effects arise due to a cantilever vibration of the whole system, and improvements can be secured by reducing the flexibility and moment of inertia of the system. In general, stiffer supports, lighter and shorter

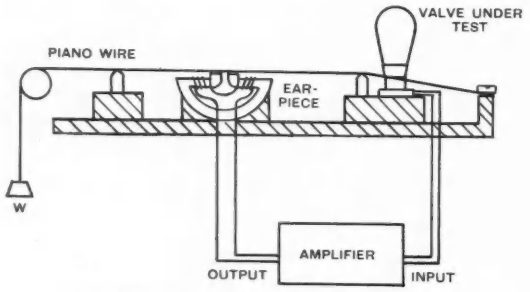


Fig.48.—Test for microphone noise.

systems, and reduced height of mounting, are all beneficial.

In the study of microphonic noises it has been found useful to employ the apparatus shown in fig. 48. The valve is mounted on a platform provided with two bridges over which a steel wire passes. The output of the valve is amplified and used to actuate a magnetic earpiece which drives the steel wire. With correct phasing the system will build up to a continuous vibration whenever the wire is tuned by means of the movable bridge to the resonant frequency of any part of the electrode system. The electrodes can now be examined with a binocular microscope, when the cause of vibration will usually be apparent.

ROBUSTNESS.

The early users of radio valves were content to treat them as delicate articles, and manufacturers generally relied on cotton-wool methods in order to ensure safety in transit. This method was made more than ever necessary by the advent of thoriated-tungsten filaments, especially when they were carbonized or of very low current consumption.

With the general introduction of oxide-coated filaments and cathodes the emissive member ceased to be the chief factor limiting mechanical strength. Improvements were secured by bonding the electrodes by means of insulating members and by the use of thicker supports from the glass "foot" or "pinch." These changes had the unfortunate effect of increasing the difficulties of the glasswork, resulting in greater wastage in manufacture. By a choice of stiffer materials such as nichrome, magno-nickel, etc., some further improvement was secured, but it was not until the system was supported at the upper as well as the lower end that a real step forward was achieved.

In the case of glass valves this was made possible by the use of glass bulbs with specially-shaped tops, generally known as "dome top bulbs" (see fig. 49). Naturally there must be some variation in the internal diameter of the dome portion of these bulbs, and in consequence a great variety of methods have been used to compensate for these variations. As shown in fig. 50, these include various designs of flexible supports of mica and metal, and the use of serrated edges designed to break off according to the diameter of the bulb. In the metal-anode valves introduced in this country in 1933 (see fig. 51) the inside of the anode became the supporting surface and, owing to the greater accuracy obtainable in a metal pressing, these devices were unnecessary.

The strength of each individual electrode can be greatly improved by the use of heavier-gauge metals.

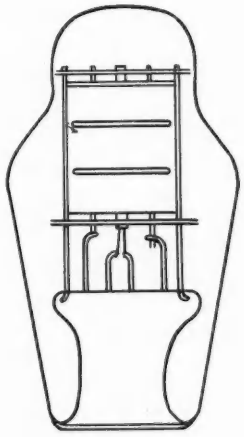


Fig. 49.

In the case of grid electrodes, however, this tendency conflicts with the technical requirements in many cases. The amplification factor (μ) of a triode valve of cylindrical form is given approximately by the equation

$$\mu = a\rho n^2 K$$

where ρ = diameter of grid wire, a = clearance between grid and anode, n = number of grid turns per unit length, and K = a constant depending on electrode form.

It is possible, therefore, to secure the same μ value by using either a heavy wire with open pitch [(*a*), fig. 52] or a fine wire with close pitch [(*b*), fig. 52]. In both cases the characteristics will be similar in the region of zero grid volts. As the anode voltage and grid bias are increased, however, it will be found that in the case of the heavy-wire grid a characteristic "tail" will more quickly become

evident. This tail is due to a failure of the grid to control the electron stream completely, and will produce second-harmonic distortion in output triodes. This effect has been dealt with earlier in the paper.

From the point of view of the characteristic, therefore, fine grid wires are desirable, and a compromise is necessary between the mechanical and electrical requirements.

FREQUENCY LIMITATION.

The maximum frequency at which a radio valve will operate is entirely controlled by the physical dimensions, configuration, and potentials, of the electrodes.

In the case of triodes used as self-oscillators the input and output capacitances are of considerable importance. Of greater importance, however, is the inductance of the electrode leads and of the electrodes themselves. Assuming that the oscillatory circuit comprises inductance only, then the wavelength can be progressively reduced until the external circuit provides insufficient coupling to maintain oscillation. Before this limit is reached the efficiency will necessarily fall away.

A third factor which must be taken into consideration is the "transit time" of the electrons, *i.e.*, the time taken for each electron to pass from the filament to the anode. When the frequency becomes so high as to be comparable with the reciprocal of the transit time a lagging effect occurs which results in the production of a difference in phase between the current and the applied voltage. At the present time these factors can be overcome to some extent by the use of close clearances between electrodes, short straight leads, and small electrodes[37]. Wavelengths as low as 40 cm. have been reached by these methods, using conventional circuits but necessarily with very small power.

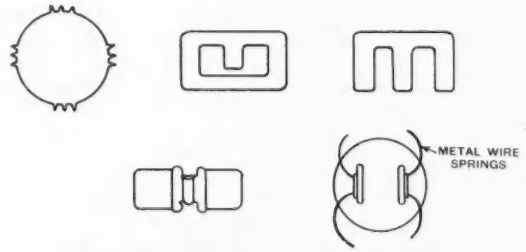


Fig 50.—Types of locating members.

While these miniature valves or "acorns" have already been mentioned by Mr. Mullard in his Chairman's Address[40], it may be of interest to give a comparison of their dimensions with those of a normal receiving valve (see Table 6).

TABLE 6.

	Acorn triode AH1	Receiving triode MH4
Cathode dimensions, mm.	10 × 0.63 (diam.)	25 × 2.7 × 1.3
Grid-cathode clearance, mm. ..	0.135	0.4
Grid-wire diameter, mm.	0.03	0.110
Grid-anode clearance, mm.	0.27	1.6
Grid-anode capacitance, $\mu\mu$F ..	1.4	4.5
Grid-cathode capacitance, $\mu\mu$F ..	1.0	7.0
Anode-cathode capacitance, $\mu\mu$F	0.6	5.0
Length of anode lead, mm.	15	65
Length of grid lead, mm.	15	65

The assembly and inspection of these very small valves necessitates the use of binocular microscopes at almost every stage. From the dimensional point

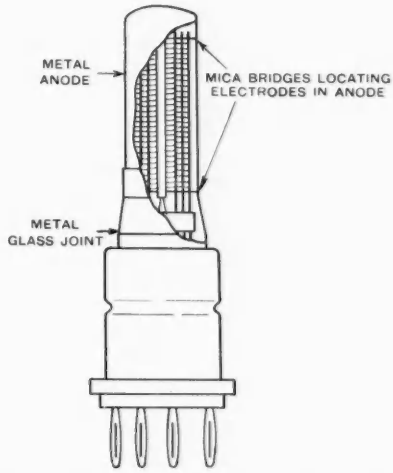


Fig. 51.—Air-cooled-anode output pentode.

of view the work is akin to that of the watchmaker. The latter, however, has a marked advantage over the valve manufacturer in that his component parts, though small, are individually rigid and can be machined to accurate limits. The manufacturing cost of acorn valves places them at present outside the range of commercial receiving practice, and, even if this were not the case, their life and general robustness could hardly be considered up to the present market standards.

When tetrode and pentode valves are used as amplifiers and if due precautions are taken to avoid circuit losses it will be found that the upper limit of frequency is set by self-oscillation. The inductance of the screen and/or suppressor-grid lead makes it impossible to earth these electrodes effectively. As a result a coupling arises between anode and grid, causing self-oscillation. Pentode valves in which the suppressor grid has been brought out at the cap are more limited in this respect than tetrodes, but if the suppressor grid is connected internally to the cathode the pentode is then equally efficient.

TESTING.

The testing of valves has always presented a real problem to the manufacturer, and it can now be said to be one of the most expensive items in manufacture. The number of electrical tests has grown steadily with time, while the complexity of test circuits has easily kept pace with them. There are, of course, certain tests which are common to all valves, and it will be as well to examine these briefly for the benefit of those engineers who are not directly engaged in manufacture.

(a) Filament Current or Voltage.

Valves intended for parallel operation either from batteries or from a.c. supplies are checked for filament current at a fixed filament voltage. A tolerance of ± 10 per cent is customary practice, although smaller limits may be desirable in special cases.

Where the design is specifically for series operation, as in the case of A.C./D.C. valves and some repeater types, a measurement of voltage at a fixed current is, of course, more usual. Here again a tolerance of ± 10 per cent may be regarded as normal. Owing to the resistance characteristics of the filament, however, the tolerance may be equivalent to only ± 5 per cent under constant-voltage conditions.

In the case of filament valves of low current consumption the anode current may represent an appreciable portion of the filament current, and the test will need to be carefully specified.

(b) Anode Current.

One of the most useful tests from the user's point of view, and also the simplest, is a measurement of anode current at some suitable working point. It has been shown earlier in this paper that the anode-current value may vary considerably even under closely-controlled manufacturing conditions. In the case of valves of considerable power dissipation, therefore, it is often good practice to adjust the grid voltage so that a predetermined anode current is obtained and to record the grid voltage as a criterion of the characteristic.

(c) Negative Grid Current.

A measurement of the negative or reverse grid current is necessary in all types of modern valves, since an excess would prove objectionable in many operating circuits. In the early days it was general practice to vary the grid-bias voltage from a high negative voltage until the maximum reverse grid current was obtained (see fig. 53). The reading so obtained was known as the "backlash." The method was objectionable, since the reading obtained depended on the positive as well as the negative grid current. To-day it is more usual to make the measurement at a point on the straight portion of the reverse grid-current curve where positive grid current will not affect the result. If the reading is taken in this way the ratio of grid current to anode current for any given type will be proportional to the gas pressure in the valve.

Among the useful tests which may be applied to valves of all types is one which tests for disconnections and for short circuits between electrodes. With modern multi-electrode valves with small clearances

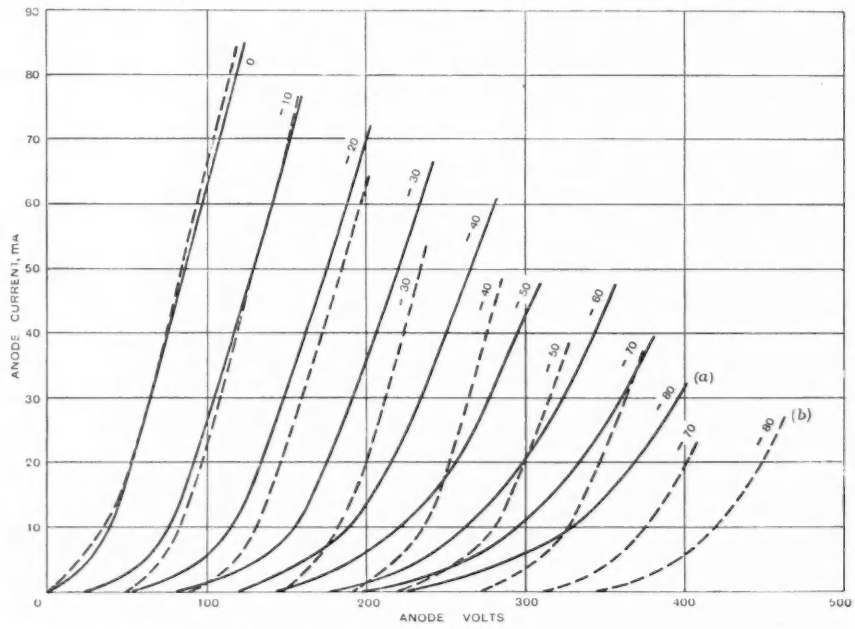


Fig. 52.—Characteristics of output triodes having grids wound with coarse and fine wires.

an occasional short circuit or broken wire will occur. Such a fault is difficult to localize on static test and may operate to delay testing or to damage meters This test, which originated in America, makes use of

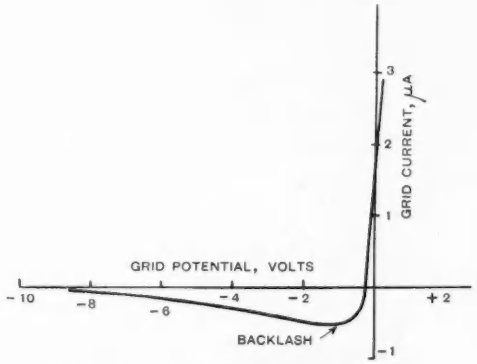


Fig. 53.—Grid-current characteristic.

a hexaphase supply connected to a ring potentiometer (see fig. 54). The cathode of the valve is connected to the centre point of the circuit, while each electrode is taken through a suitable neon lamp to an appropriate tapping-point on the potentiometer. With the cathode hot, each neon lamp will glow on one electrode (see fig. 54) and a disconnection will result in one or more of the neon lamps being extinguished. Should a short circuit occur between any two electrodes the neon lamps associated with them will glow on both electrodes.

To this test must be added special tests applying to a limited number of types. In the case of amplifying valves it is necessary to measure mutual conductance at the operating point, while those types having variable-mu control must have the measurement repeated at a sufficiently high negative bias to ensure that correct "tail" characteristics are present. These measurements are best made by an A.C. method. A known A.C. voltage is applied to the control grid, and the A.C. component of the anode current is separated from the D.C. and read off directly on a suitable meter. Precautions are necessary in this test to ensure that the A.C. load impedance in the anode circuit is effectively zero.

Output pentodes and triodes are conveniently tested for power output by a similar method using a resistive anode load of the correct value for the particular type. In this case, however, the grid swing applied must cover the full operating range.

Types of amplifying valve with "straight" characteristics are normally tested for "cut off" to ensure that no undesirable characteristic tail is present. This test is usually made at a fixed negative grid-bias, and a maximum limit for anode current is set. Such a test is particularly desirable with types used for anode-bend detection.

Heptode frequency-changer valves must, of course be tested for conversion conductance, and there are two excellent methods available. The first, a low-frequency test, can be made on the 50-cycle supply. It consists in supplying the oscillator grid with its appropriate peak voltage via a grid leak and condenser of suitable value (see fig. 55). An A.C. voltage of the same frequency, but of small amplitude (say, 1 volt), is simultaneously applied to the signal grid, and the D.C. anode current is recorded on a moving-coil meter. The signal-grid voltage is now reversed in phase and the anode current again recorded. The difference between the two readings expressed in milliamps., divided by twice the peak voltage applied to the signal grid in volts, gives an accurate value for the conversion conductance. A separate oscillatory test at high frequency is necessary for the triode section.

The second method, which is more rapid in use, is carried out at high frequency. In this case the oscillator section is connected to a suitable circuit so that it may generate its own appropriate peak voltage. A known signal voltage of appropriate frequency is applied to the signal grid, and the resulting intermediate-frequency signal in the anode circuit is recorded directly by means of a valve voltmeter. This method, though more rapid than the low-frequency test, suffers from the disadvantage that it is not absolute and frequent calibration is necessary.

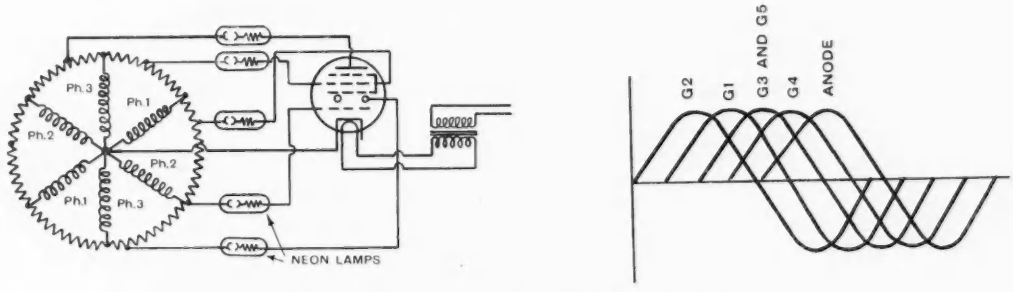


Fig. 54.—Short circuit and open circuit test.

One of the most difficult requirements to meet in modern valves is that of freedom from noise. The noise test needs to be included in the tests made in the producing department, in order that quick action may be taken when rejects occur. The most suitable test is that made in a receiver of the type most usually employed for the particular valve under test, and precautions are necessary to avoid the interference always present in a valve factory. To this end the whole receiver chassis may be enclosed in an earthed metal box with the one test position brought outside with screened leads. This enables the valve to be handled and to be subjected to tapping in order to indicate any looseness in the system.

As a precautionary measure it has been found desirable for many years to repeat the tests, including the noise or "chassis" test, on all valves before despatch. This second test eliminates any cases of slow air leak which may occur, and also provides

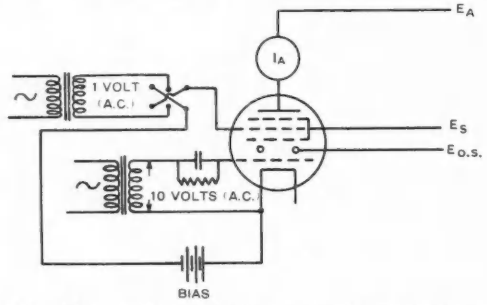


Fig. 55.—Conversion conductance test for heptode valves.

a check on general accuracy. To avoid disputes over borderline cases the section or factory limits are best set to a slightly narrower tolerance than those used on final inspection.

No modern valve factory would be complete without a very complete equipment for life test. Such tests call for a very rigid routine to ensure that all types are tested as soon as possible after manufacture, while the racks used must be flexible in order to deal with new valve types and altered conditions for existing types. The collection of life-test valves is best carried out under separate control, divorced from actual manufacture, and however small the quantity made a certain minimum number should be tested each week. When manufacture is carried out in large numbers a percentage, varied on a sliding scale, is desirable.

FUTURE DEVELOPMENTS.

In considering what may be the future developments in radio receiving valves it is useful to review the tendency in past years. In this country the main effort of most manufacturers has been to secure the greatest possible degree of efficiency from each valve. This policy, dictated by competition, has resulted in the frequent introduction of new types and a general lack of standardization between the products of various manufacturers. Such competition has made the attainment of economical and accurate production difficult, and, moreover, the short active life of individual types hindered the study and correction of faults arising in service. During the last year or two there has been some abatement in the rush of new types and a more intensive concentration by manufacturers on such factors as reliability, uniformity and economy.

As improvements in materials and technique become available it is usually possible to employ them either to secure higher levels of characteristic or to increase the economy of the product at the standard of performance existing at the time. From present indications it would appear that both these lines of attack are likely to continue to be followed. At the present time the radio industry in this country would appear to be entering a period of more intensive competition than ever before, and manufacturers will strive to secure the best value of performance for a given cost while retaining a satisfactory level of reliability and uniformity.

It would appear that there is still room for improvement in valves used for the shorter wavelengths, particularly in the region between 6 and 8 metres, which is now of such interest for television purposes. One of the items outstanding in this direction and which is receiving much attention at the present time is the frequency-changer.

Existing frequency-changers, particularly those of the triode hexode type, will operate reasonably well down to 5 or 6 metres if precautions are taken in the circuit layout to avoid undue inter-circuit coupling. Operation down to 3 metres may, however, become necessary if a number of television transmitters have to be accommodated in a restricted area.

A further item of considerable interest at the present time is the provision of valves suitable for wide-band amplifiers. The present tendency is to employ high-frequency pentode valves in which the ratio of mutual conductance to input and output capacitances is as great as possible. By reason of the low impedance of the anode load, usually employed to obtain the wide frequency coverage, the grid-anode leakage capacitance of the valve is of much less importance than in valves used with high-impedance tuned circuits, and may be allowed to rise to a value approaching 100 times the figure usually necessary in the latter types.

A practical instance of this is given by the N43 valve. This is a development of the high-slope output pentode type N41, and has been fitted with earthed screens at the ends of the system and a top grid-connection to reduce the leakage capacitance between anode and grid (figs. 26 and 43).

This treatment has not resulted in any appreciable loss of mutual conductance but has reduced the grid-anode capacitance from more than $1\mu\mu F$ to the neighbourhood of $0{\cdot}2\mu\mu F$. While this latter figure is very high by comparison with that for normal high-frequency pentodes, it is yet low enough for the wide-band type of amplifier.

In considering future developments in radio receiving valves mention must be made of the possibilities of the use of secondary emission. Practical demonstration has already been given of a secondary-emission multiplier operating from a light source and giving a marked improvement in signal/noise ratio. It seems probable, however, that if a grid electrode were introduced before the first collector, so that normal amplification became possible, the advantages in respect of noise would disappear. Such an arrangement would make possible a very high order of amplification in a very small space and would offer many advantages in the rather limited field of high-gain amplifiers. In radio receivers of to-day, however, and particularly in the superheterodyne receiver, valves are used to secure selectivity as well as amplification, and it is very difficult to imagine a single multiplier which would replace the functions of the high-frequency amplifier, frequency-changer, intermediate-frequency amplifier, second detector, and low-frequency amplifier.

The science of electron optics has been studied for many years and is essential to the design of cathode-ray devices. It is only quite recently, however, that serious attention has been given to the design of amplifiying devices based on the principle of deflecting a beam of electrons rather than controlling the intensity of an electron stream, and up to the present there have been no outstanding developments along these lines, except in very specialized cases.

Many advances in valve efficiency have in the past been brought about by improvements in the emission efficiency of the cathode. It is the view of the authors that the oxide cathode has to-day reached a very high plane, and it is unlikely that any major improvement will be realized in this direction. Caesium cathodes, which have been referred to elsewhere in this paper, have been carefully explored by many investigators; although under certain limited conditions of use they may give much greater efficiency than the oxide type, there would appear to be no immediate prospect of their use in practical radio valves.

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Automatic Power Station Equipment in South Africa.

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In this article the author describes apparatus which has been installed in the generating station of the South African Iron and Steel Industrial Corporation Ltd., at Pretoria, whereby the station load and its power factor are controlled automatically.

INTRODUCTORY.

SOME years ago, in order to meet the demand for converting sub-stations which would operate without attendance, efforts were directed to the development of gear by means of which all normal control and switching operations in connection with the converting units would be carried out automatically, and this gear has operated so satisfactorily that the automatic operation of converting sub-stations is now standard practice. The case is different, however, where attendants are available, as in steam generating stations. Although automatic protection against faults has been in use for many years, little attempt has been made until recent years to use automatic control during normal running. Almost the only exception to this has been the generator voltage regulator, but now a tendency is evident in the direction of much greater use of automatic control, as there is a number of operations which can be carried out with considerable precision by the use of automatic gear, leaving attendants free for other duties. For this purpose, the class of gear used in automatic sub-stations has been found very useful. An interesting example of such an application is described in this article.

SOUTH AFRICAN IRON AND STEEL INDUSTRIAL CORPORATION.

The South African Iron and Steel Industrial Corporation, Ltd., known as Iscor, in which the Union Government is a large shareholder, was formed in 1928 in recognition of the importance of the primary iron and steel industry to South Africa, and as a result a comprehensive and modern works,

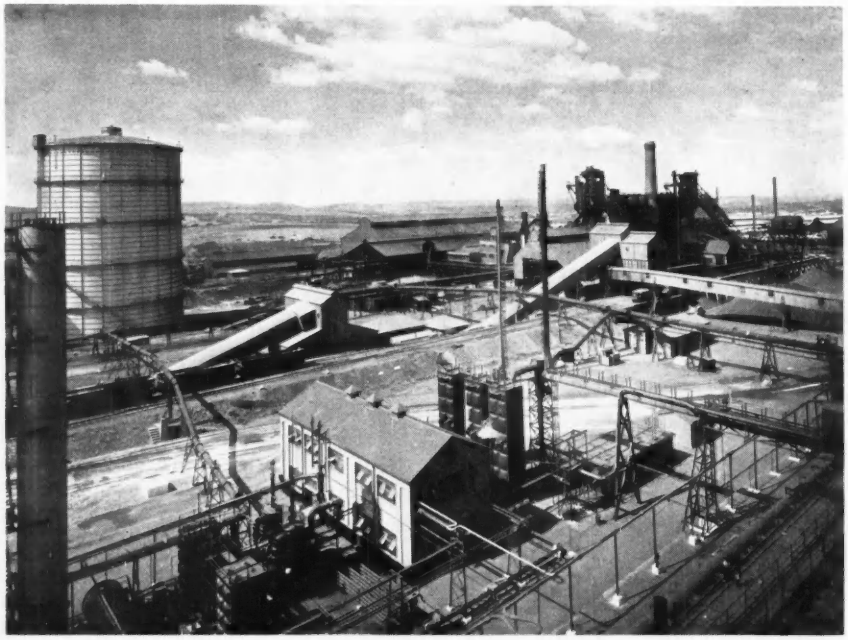


Fig. 1.—General view of Iscor Works of the South African Iron and Steel Industrial Corporation.

of which fig. 1 is a general view, was erected at Pretoria. This plant, with ample resources in high-grade ore, coking coal, and practically every raw material required for the production of iron and steel, is capable of turning out 325,000 tons of steel ingots a year and of converting these into a wide range of primary finished products. Production began in 1934 and since that date has rapidly increased so that to-day not only is Iscor supplying steel for existing needs such as the railways, the mining industry and the building trades : it is also providing the raw material for secondary industries and stimulating the industrial development of South Africa.

ELECTRICAL PLANT AT ISCOR.

The steelworks possesses a generating station which supplies part of the load, whilst a further supply is taken from the Pretoria municipal power station, as shown in fig. 2. Feeders connect the Pretoria station to the Ilgner House sub-station and Ilgner House to the Iscor station, which at present contains three turbo-alternators. Each alternator is rated at 3,000 kW normal load or 5,000 kW maximum load, generating at 11·5 kV., three phase, 50 cycles, and running at 3,000 r.p.m. Under the tariff arrangement with the municipality, the price paid for the purchased energy depends on the maximum half-hour kVA demand every month. It is thus important that the agreed demand be not exceeded, and to this end automatic gear has been installed at the Iscor station by which the following main operations are carried out :—

(*a*) The power demand on Pretoria is kept constant, the fluctuation of load being taken by the Iscor Station. This is subject, however, to the exception that automatic control of the generators is interrupted if the total load on them falls to a predetermined low level ; this is to avoid risk of these machines being motored.

(*b*) The load is shared equally between those generators which are running at any time at Iscor.

(*c*) The power factor of the purchased supply is maintained at unity, the whole of the wattless kVA thus being supplied by Iscor.

(*d*) The wattless kVA is shared equally between those generators which are running at any time at Iscor.

Actions (*a*) and (*b*) are obtained by control of the governor gear of the turbines, and (*c*) and (*d*) by adjustment of the exciter fields. In the event of the two power systems being disconnected, the automatic gear operates in such a way that control of the total power and total wattless kVA generated at Iscor is arrested. Load sharing continues, but the control of the exciter fields is transferred to automatic voltage regulators, which are designed for reactive kVA sharing as well as voltage regulation. If desired, the exciter fields may be changed over to the voltage regulators during normal running.

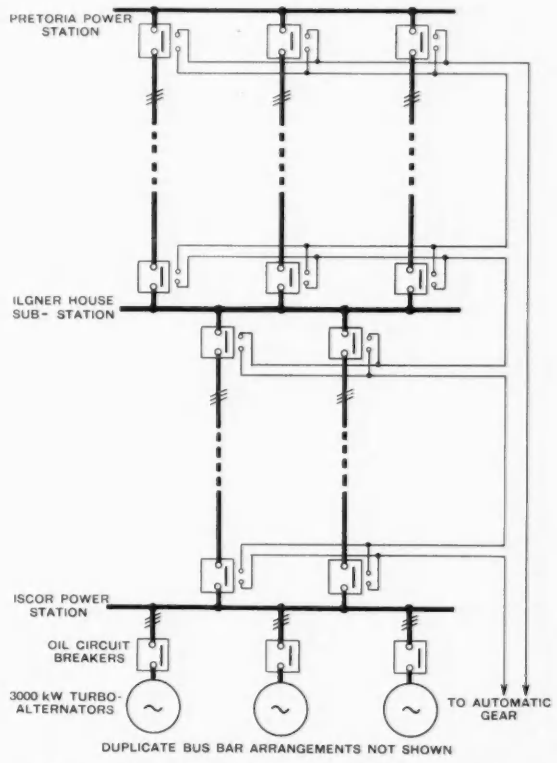


Fig. 2.—Simplified diagram of the power system.

Both the load control gear and the power factor control gear consist essentially of two portions, *viz* :—

(1) The main regulating gear.

(2) The auxiliary gear operating in conjunction with the above to give the necessary flexibility of control, and indication and warning of emergency conditions (such as disconnection of the two systems), and to prevent incorrect operation under such conditions.

Certain parts of (2) are common to the load control and the power factor control.

MAIN REGULATING GEAR.

The action of the main regulating gear is generally similar for the two sections. The principle* is shown in fig. 3. Load control is effected through the agency of a main load control relay responsive to the load on Pretoria, in conjunction with load sharing relays, one of which is associated with each alternator. The main relay makes one or other of its contacts if the total load on the purchased supply varies above or below its correct value, resulting

* British Patent Numbers 360,593 and 425,161.

in the energization in the appropriate direction of the "additional voltage coils" of the load sharing relays, which latter are designed to be sensitive only to the wattful components. This in turn results in movement of these relays and the sending out of

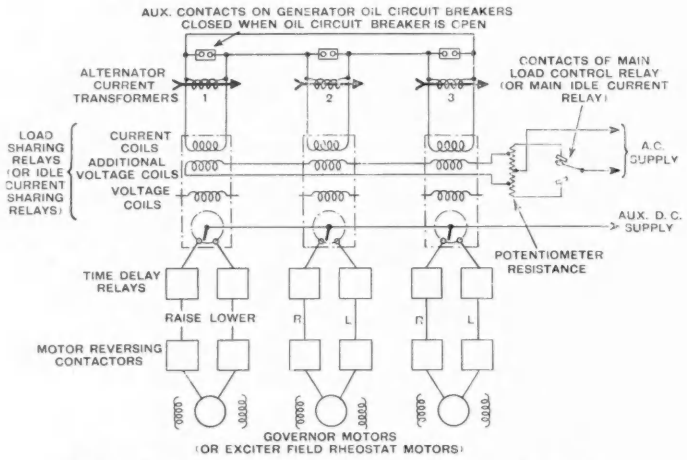

AUX. CONTACTS ON GENERATOR OIL CIRCUIT BREAKERS CLOSED WHEN OIL CIRCUIT BREAKER IS OPEN
ALTERNATOR CURRENT TRANSFORMERS
1
2
3
CONTACTS OF MAIN LOAD CONTROL RELAY (OR MAIN IDLE CURRENT RELAY)
LOAD SHARING RELAYS (OR IDLE CURRENT SHARING RELAYS)
CURRENT COILS
ADDITIONAL VOLTAGE COILS
VOLTAGE COILS
A.C. SUPPLY
AUX. D.C. SUPPLY
POTENTIOMETER RESISTANCE
TIME DELAY RELAYS
RAISE LOWER
MOTOR REVERSING CONTACTORS
GOVERNOR MOTORS (OR EXCITER FIELD RHEOSTAT MOTORS)

Fig. 3.—Elementary diagram of main regulating gear.

impulses *via* time delay relays which energize the governor motor contactors, causing the necessary adjustment to be made to the turbine governor gear setting to restore the load on Pretoria to its correct value. Load sharing is effected by the current coils of the load sharing relays. These coils are each connected across the secondary of a current transformer, the primary of which is in the alternator output circuit. These secondaries are connected in series to form a complete ring. If all the generators are supplying the same current, the same secondary current simply circulates in the closed ring, but if the current from any one machine is different from that of the others, a difference current flows from the current transformer concerned. This current divides into two paths, one through the winding of the relay connected across its terminals, and the other through the windings of the other relays in series. Thus, with three alternators in parallel, two-thirds of the out-of-balance current passes in one direction through the relay associated with the particular generator, while one-third out-of-balance current in the "reverse" direction passes through the others. The result is that the relay connected to the abnormal generator operates in one direction, while the others operate with a weaker force in the opposite direction.

Power factor control operates in an analogous manner. Operation is initiated by a main idle current relay which operates through idle current sharing relays, to control the exciter field rheostat motors, in order that the excitation of the local generators may be so regulated that they supply the reactive component of the steelworks load. The idle current sharing relays are similar to the load sharing relays, except for being sensitive to wattless power.

Having given an outline of the main scheme of regulation, the circuits and apparatus will now be described in detail under the headings previously given, and with reference to the sequence diagram fig. 4 and the schematic diagram, fig. 5. The automatic gear is mounted on two panels, as shown in figs. 6 and 7. The left-hand panel carries the load control gear and the right-hand the power factor gear.

(*a*) *Main Load Control.*

The load regulating relay is of the 2-element induction wattmeter type with coil connections similar to those of a 3-phase watthour meter. The torque of the discs is balanced against a control spring, a setting adjustment being provided. The current coils are connected in the current supply which is summated

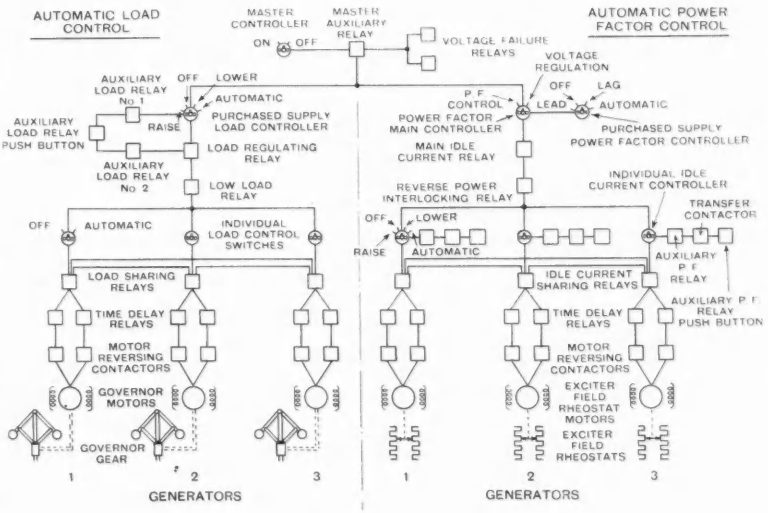


Fig. 4.—Sequence diagram.

from the incoming feeders at Ilgner House, and the potential coils are fed from the Ilgner House instrument potential supply. The relay is thus responsive to the purchased load, and upon the latter deviating from its correct value, the relay contacts energize the load sharing relays through a potentiometer resistance. This operation is effected provided that (1) the purchased supply load controller is set for automatic control, (2)

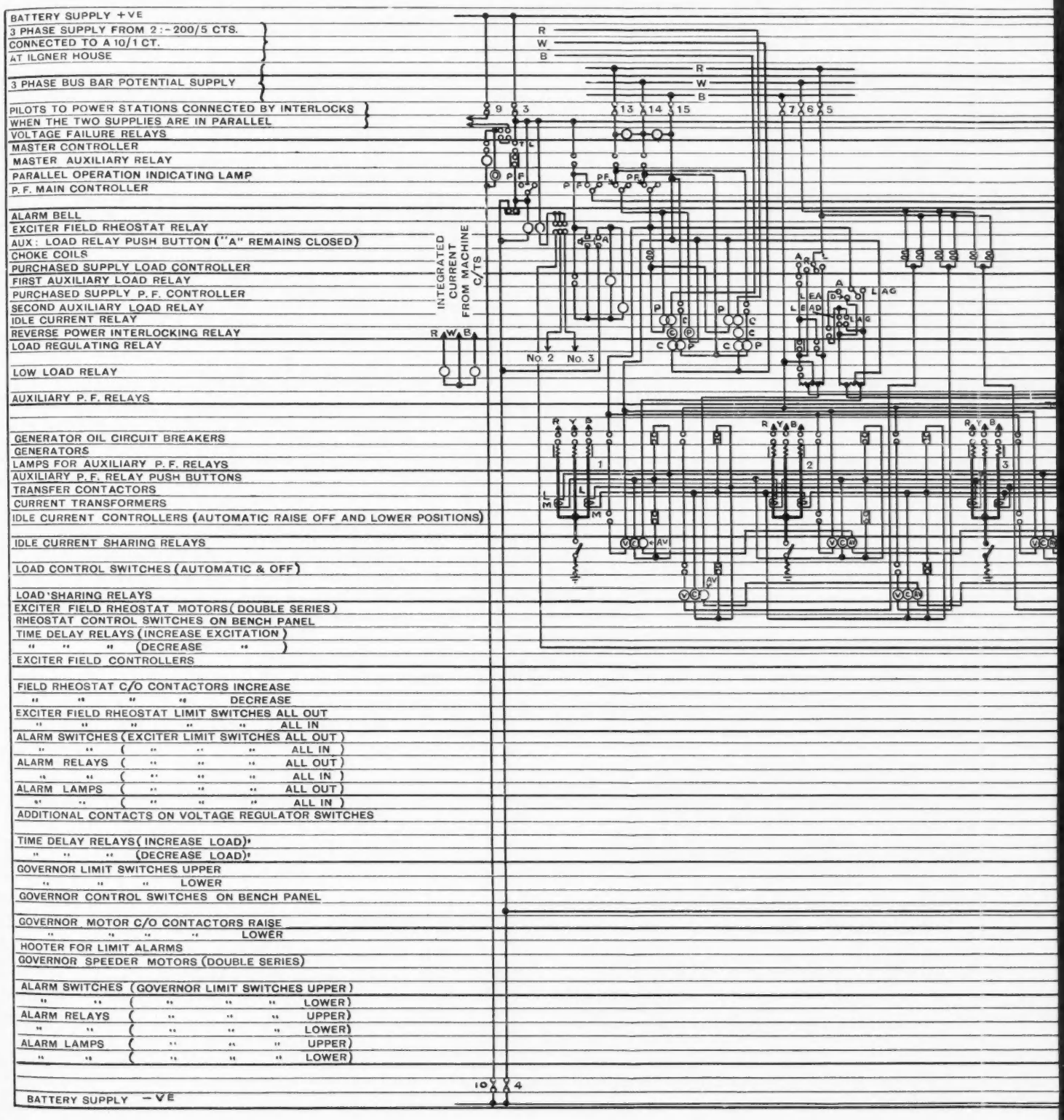
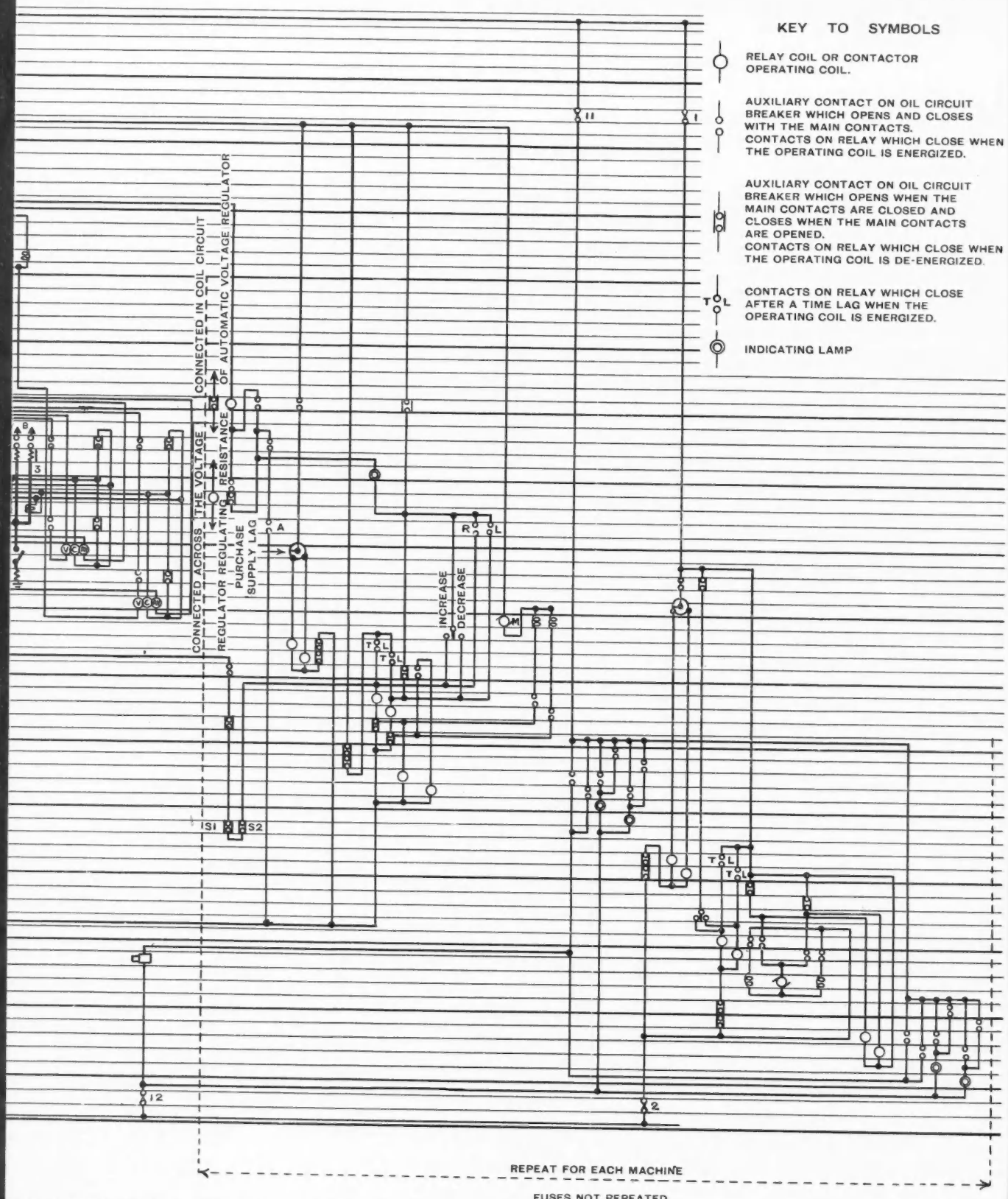

BATTERY SUPPLY +VE
3 PHASE SUPPLY FROM 2:-200/5 CTS. CONNECTED TO A 10/1 CT. AT ILGNER HOUSE
3 PHASE BUS BAR POTENTIAL SUPPLY
PILOTS TO POWER STATIONS CONNECTED BY INTERLOCKS WHEN THE TWO SUPPLIES ARE IN PARALLEL
VOLTAGE FAILURE RELAYS
MASTER CONTROLLER
MASTER AUXILIARY RELAY
PARALLEL OPERATION INDICATING LAMP
P. F. MAIN CONTROLLER
ALARM BELL
EXCITER FIELD RHEOSTAT RELAY
AUX: LOAD RELAY PUSH BUTTON ("A" REMAINS CLOSED)
CHOKE COILS
PURCHASED SUPPLY LOAD CONTROLLER
FIRST AUXILIARY LOAD RELAY
PURCHASED SUPPLY P. F. CONTROLLER
SECOND AUXILIARY LOAD RELAY
IDLE CURRENT RELAY
REVERSE POWER INTERLOCKING RELAY
LOAD REGULATING RELAY
LOW LOAD RELAY
AUXILIARY P. F. RELAYS
GENERATOR OIL CIRCUIT BREAKERS
GENERATORS
LAMPS FOR AUXILIARY P. F. RELAYS
AUXILIARY P. F. RELAY PUSH BUTTONS
TRANSFER CONTACTORS
CURRENT TRANSFORMERS
IDLE CURRENT CONTROLLERS (AUTOMATIC RAISE OFF AND LOWER POSITIONS)
IDLE CURRENT SHARING RELAYS
LOAD CONTROL SWITCHES (AUTOMATIC & OFF)
LOAD SHARING RELAYS
EXCITER FIELD RHEOSTAT MOTORS (DOUBLE SERIES)
RHEOSTAT CONTROL SWITCHES ON BENCH PANEL
TIME DELAY RELAYS (INCREASE EXCITATION)
" " " (DECREASE ")
EXCITER FIELD CONTROLLERS
FIELD RHEOSTAT C/O CONTACTORS INCREASE
" " " " DECREASE
EXCITER FIELD RHEOSTAT LIMIT SWITCHES ALL OUT
" " " " " ALL IN
ALARM SWITCHES (EXCITER LIMIT SWITCHES ALL OUT)
" " (" " " ALL IN)
ALARM RELAYS (" " " ALL OUT)
" " (" " " ALL IN)
ALARM LAMPS (" " " ALL OUT)
" " (" " " ALL IN)
ADDITIONAL CONTACTS ON VOLTAGE REGULATOR SWITCHES
TIME DELAY RELAYS (INCREASE LOAD)
" " " (DECREASE LOAD)
GOVERNOR LIMIT SWITCHES UPPER
" " " LOWER
GOVERNOR CONTROL SWITCHES ON BENCH PANEL
GOVERNOR MOTOR C/O CONTACTORS RAISE
" " " " LOWER
HOOTER FOR LIMIT ALARMS
GOVERNOR SPEEDER MOTORS (DOUBLE SERIES)
ALARM SWITCHES (GOVERNOR LIMIT SWITCHES UPPER)
" " (" " " LOWER)
ALARM RELAYS (" " " UPPER)
" " (" " " LOWER)
ALARM LAMPS (" " " UPPER)
" " (" " " LOWER)
BATTERY SUPPLY -VE
INTEGRATED CURRENT FROM MACHINE C/TS
No. 2
No. 3
LEAD
LAG

Fig. 5.—Main schematic diagram of automatic power station equipment at the generating statio


KEY TO SYMBOLS
RELAY COIL OR CONTACTOR OPERATING COIL.
AUXILIARY CONTACT ON OIL CIRCUIT BREAKER WHICH OPENS AND CLOSES WITH THE MAIN CONTACTS.
CONTACTS ON RELAY WHICH CLOSE WHEN THE OPERATING COIL IS ENERGIZED.
AUXILIARY CONTACT ON OIL CIRCUIT BREAKER WHICH OPENS WHEN THE MAIN CONTACTS ARE CLOSED AND CLOSES WHEN THE MAIN CONTACTS ARE OPENED.
CONTACTS ON RELAY WHICH CLOSE WHEN THE OPERATING COIL IS DE-ENERGIZED.
T L
CONTACTS ON RELAY WHICH CLOSE AFTER A TIME LAG WHEN THE OPERATING COIL IS ENERGIZED.
INDICATING LAMP
CONNECTED IN COIL CIRCUIT OF AUTOMATIC VOLTAGE REGULATOR
CONNECTED ACROSS THE VOLTAGE REGULATOR REGULATING RESISTANCE
PURCHASE SUPPLY LAG
INCREASE
DECREASE
R L
M
T L
S1
S2
11
1
12
2
REPEAT FOR EACH MACHINE
FUSES NOT REPEATED

ating station of the South African Iron and Steel Industrial Corporation at Pretoria.

the first auxiliary load relay is closed, so checking that the power stations are fully interconnected, and (3) the contact of the low load relay is closed. These various devices are described later.

The low load relay shown in fig. 8 has a double solenoid and controls the position of a beam, which is balanced but has topple movement. There is one contact only, which breaks when the load falls below the setting figure; automatic control is thereby cut off, but recommences upon the generator load exceeding this setting figure. The supply for the coils is summated from the generator current transformers. The coils are connected in open delta, regulation thus being on the mean of unbalanced currents. Adjustment is by the milled nut in the slot on the beam.

The load sharing relay, illustrated in fig. 9, has a single phase watthour meter element with the current and potential fluxes arranged in quadrature at unity power factor by the use of two external chokes. The current element has two sets of coils. The current coils (marked C on the diagram) are energized by the out-of-balance currents, and the additional voltage coils (AV) are controlled by the main load regulating relay for group operation. These two sets of coils react with the voltage coils (V) to produce a torque in a direction depending on the

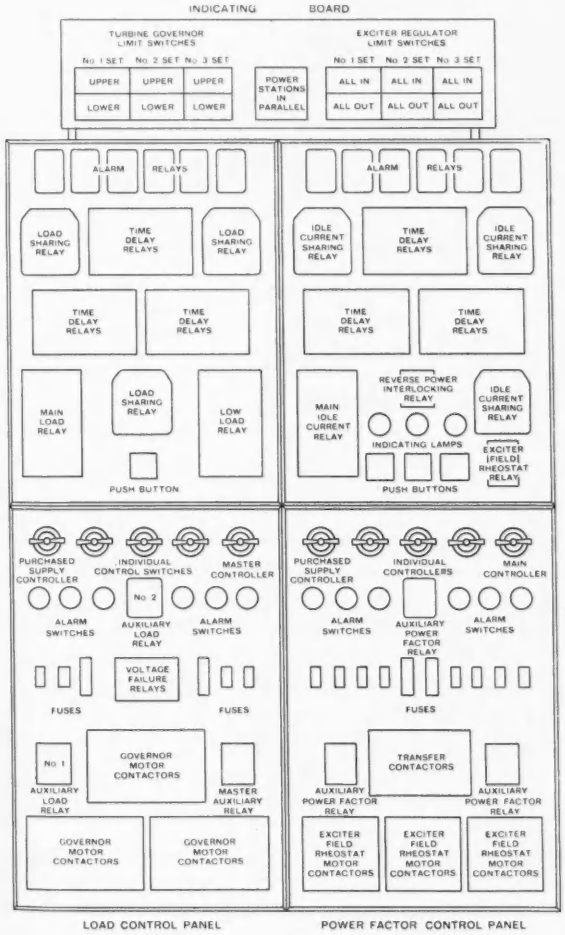


Fig. 6.—Front elevation of control panels.

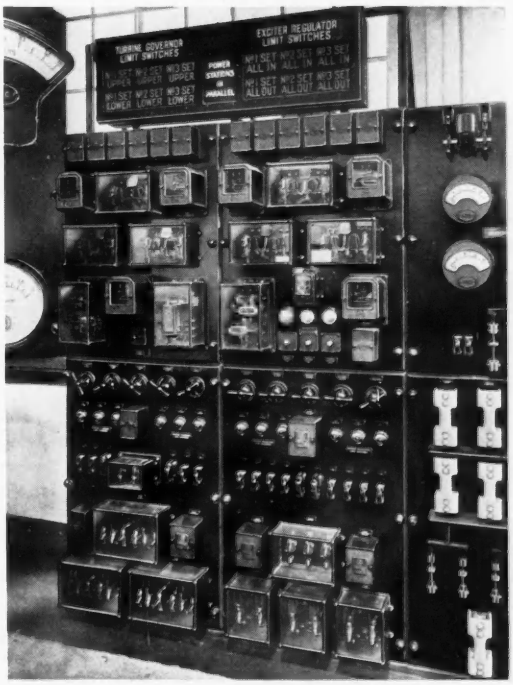


Fig. 7.—Control panels on site.

demand to increase or decrease the load. The relay disc is arranged for continuous rotation in either direction, and the control force is provided by a spring-loaded crank. The setting of the crank spring is adjustable. Strikers on the disc spindle cause the contact arm to make one contact or the other, depending on the direction of rotation of the disc.

When the additional voltage coils of these relays are energized, the relay disc rotates in the appropriate direction, and during a small portion of each revolution makes one of its contacts, which, by means of its corresponding time delay relay, makes a contact to operate the governor motor for a definite time. By this means the regulation is done in steps, so as to prevent hunting. The time delay relay which provides the stepping feature consists of a contactor movement which when energized winds up a clockwork mechanism and immediately breaks its own circuit so that timing is obtained by the return of the clockwork mechanism under the influence of a spring. The self-breaking contact on the time delay relay also breaks the circuit of the time delay relay for the reverse operation, and in addition the reversing contactors which energize the governor motor

are mechanically interlocked, so that the possibility of both contactors being energized simultaneously is doubly prevented.

Unbalance of loading of the alternators energizes the current coils in the way previously described, the resulting actions thereafter being as for group load control. Group load control and load sharing can take place simultaneously. Interlocks on the generator oil circuit breakers and on the individual load control switches are arranged so that the voltage coil is open circuited and the current coil is short circuited if a generator is not required to take part in load control.

(*b*) *Power Factor Control.*

The power factor of the purchased supply is kept at unity by the action of the main idle current relay, which is designed to operate on EI $\sin\phi$ on unbalanced loads. The relay is shown in fig. 10. It is of the 2-element induction wattmeter type having coil connections similar to those of the load regulating relay except that the potential coils are connected with the voltage vectors rotated 90°, so that a maximum torque is obtained at zero power factor. This correct phase value of the voltage is obtained by means of an external choke which, with the two relay potential coils, makes up a balanced star circuit. The discs are controlled by a centre zero spring which allows the movement to deflect an amount proportional to the torque of the drive. When the purchased supply leads, the discs are deflected to the left, and when the supply lags, the discs are deflected to the right, in each case making the appropriate contact.

The contacts, which are adjustable, energize the idle current sharing relays through a potentiometer resistance providing that (1) the purchased supply power factor controller is in the automatic position, (2) the power factor main controller is set for power factor control, and (3) the master auxiliary relay is closed to check that the power stations are fully interconnected. The idle current sharing relays are identical with the load sharing relays previously described, but the external connections are arranged so that the fluxes of the current and potential elements are in phase at unity power factor. Maximum torque is thus obtained at zero power factor. The coils (AV) of the idle current sharing relay, which are connected to the potentiometer resistance react with the voltage coils (V) so as to produce rotation of the relay disc in a direction depending on the demand to raise or lower the excitation. The relay rotates continuously on the occurrence of a demand to change. This action, however, is changed to a step-by-step motion by means of the time delay relays, as explained in connection with load control, so that the rheostat motors are inched till the necessary correction has been made. Sharing and group control can take place simultaneously.

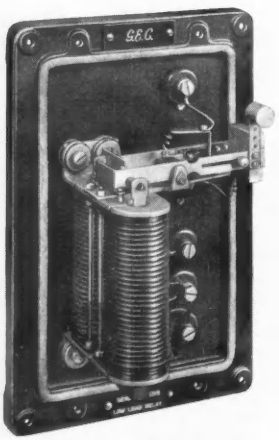


Fig. 8.—Low load relay.

AUXILIARY GEAR.

There is more auxiliary apparatus associated with power factor control than with load control; this is largely because the alternative control of the exciter fields by the voltage regulators necessitates very complete interlocking. The sequence of operation of the essential items of auxiliary gear can be followed from fig. 4, whilst fig. 5 shows the whole of the connections.

Equipment for Manual Control.

Manual control of the purchased load is provided by a four-position controller, which will remain in two positions, *viz :* "automatic" and "off," and has a spring return from the other two positions, "raise" and "lower." The first-mentioned position is used for automatic control, while for manual control the controller is turned to either the "raise" position or the "lower" position, held there till the required change has taken place, and then allowed to spring-return to the "off" position. In any of the manual positions, the circuits of the main load relay contacts are interrupted. This means of control operates through the load sharing relays and time delay relays, load sharing thus remaining operative.

Manual control of the power factor of the purchased load is obtained by means of a controller of the same type as that just described, and similarly connected. Whilst manual adjustments are being made the automatic group control is cut off, but automatic idle current sharing proceeds in the usual way.

The automatic control of individual machines can be isolated. In the case of load control, each machine is provided with a two-position load control switch. In the "automatic" position the coils of the corresponding load sharing relay are in circuit, while in the "off" position the circuit of the governor motor control switch on the generator bench panel

is prepared, so that direct control may be obtained.

For the corresponding individual control of idle current, each machine has associated with it a four-position controller, of the same type as that used for group control. In the "automatic" position the circuits of the idle current sharing relay coils are made, and the circuit of the auxiliary power factor relay is prepared. The operation of this auxiliary relay will be dealt with in the next paragraph. When the controller is out of the "automatic" position the idle current sharing relay and the coil of the auxiliary power factor relay are isolated, and further movement of the controller to either the "raise" position or the "lower" position closes the circuit of the exciter field rheostat contactors to strengthen or weaken the excitation of the generator. The contacts of the rheostat control switch on the generator bench panel are in parallel with the manual

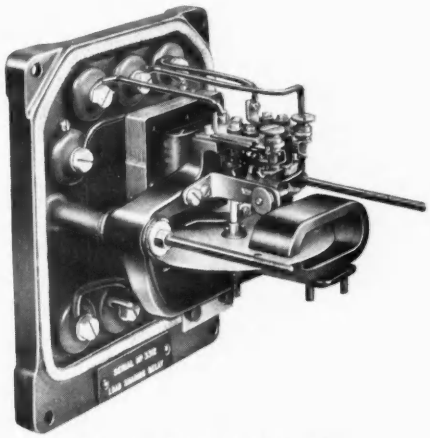


Fig. 9.—Load sharing relay.

contacts of the controller and both sets of contacts are isolated by the auxiliary power factor relay when working automatically.

Isolation of the Two Power Systems.

In order that the required operations may take place when, for any reason, the two power systems become isolated, the pilot wires shown in fig. 2 are provided between Iscor Power Station and Ilgner House, and between Ilgner House and Pretoria; it will be seen that there is a circuit through these pilots only when the two systems are running in parallel. Indication of this condition is given by a pilot lamp, and the operation of the master controller energizes the master auxiliary relay which feeds the two auxiliary load relays and the three auxiliary power factor relays. In initiating automatic control, these relays are energized by pressing respectively the auxiliary load relay push button and the auxiliary power factor relay push buttons (indicating lamps being provided in the case of the latter, to show the attendant that the circuits have been prepared), and in both cases the relays hold themselves closed and maintain contacts for energizing the circuits of the automatic gear. These arrangements ensure suspension of automatic working if the systems become isolated, and make it necessary to perform initiating operations before it can be restored.

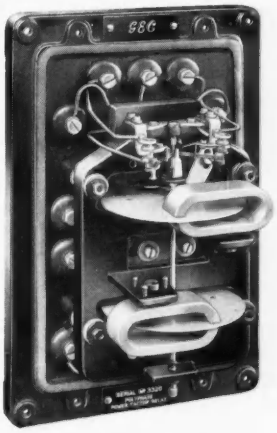


Fig. 10.—Main idle current relay.

Automatic Voltage Regulation.

The voltage regulators come into operation on isolation of the power systems, or at any other time when required. In both cases the automatic power factor control is made inoperative and the exciter field rheostats are run to the "all out" position. enabling the automatic voltage regulators to have full control of the field. These operations are carried out automatically in the following manner. Isolation of the power systems causes the opening of the master auxiliary relay, thus cutting off the voltage coil supply to the idle current sharing relays and dropping out the auxiliary power factor relays, which latter action energizes the coils of the voltage regulators. The exciter field rheostat relay is picked up to energize the "increase" field rheostat contactors, and as each rheostat reaches its "all out" position the motor feed is cut off by a limit switch set just ahead of the normal limit switch.

A bell alarm is given immediately the power systems are isolated, and this can be stopped by moving the master controller to the "off" position. Under this condition the exciter field rheostat relay holds itself closed until all the field rheostats reach the "all out" position. It is necessary, however, to ensure that the rheostat is not cut out if the voltage regulator is out of commission. This is effected by additional contacts fitted to the voltage regulator switches and in series with the "increase" circuit; the main pole of one of these switches is in the regulator coil circuit, whilst the other short circuits the regulator resistance.

It may here be pointed out that the master controller incorporates a time lag device so that its

"alarm" contacts close after the other pair. This is in order that when it is moved to the operating position, the master auxiliary relay shall have time to lift, so preventing a feed being given incorrectly to the exciter field rheostat relay.

To transfer the generators from automatic power control to automatic voltage regulation whilst the systems are still in parallel, the power factor main controller is moved to the "voltage regulation" position. This has the same effect on the power factor gear only, as the dropping out of the master auxiliary relay. If it is desired to change back to power factor control, it is necessary to insert resistance in the exciter field circuit by operating the rheostat by means of the individual idle current controllers, and, when the automatic voltage regulator has cut its resistance out, to start the automatic gear in the normal way. Transfer contactors, sensitive to the voltage across the voltage regulator resistances, are used to prevent the change being made until the regulator has been cut out in the way just described. Provision is made to obviate the possibility of the exciter field rheostat being left in the "all out" position with the automatic voltage regulator isolated after a generator has been shut down. For this purpose additional contacts are fitted to the exciter field controller. This controller has normal contacts, not shown in the diagram, for controlling and re-magnetizing the field, and for tripping the generator oil circuit breaker. The additional pairs of contacts are three in number, the first pair being arranged to insert all the exciter field resistance on shutting down, the second to break the "all out" circuit before the "all in" circuit is made, and the third to prevent the "all in" alarm from sounding.

Paralleling Alarm.

As previously mentioned, a bell alarm is given should the two power systems become isolated. The bell is switched out by means of the master controller, and thus automatic control cannot be re-established without the re-insertion of the alarm. Lamp indication is given in the main lamp indicator and is independent of the position of the master controller.

Miscellaneous Interlocking.

There are periods when the steelworks feeds a small amount of power back to the Municipality. A careful study of the scheme will reveal the fact that during such reversals the power factor control equipment would not keep the power factor at unity, but instead would change the excitation to increase the idle kVA. This condition is guarded against by means of the reverse power interlocking relay, which cuts off main power factor control, but not idle current sharing, when Iscor feeds back to Pretoria. The relay is of the single-element induction type, connected to act as a three phase balanced load (two current coil) power relay, and breaks the "automatic" circuit of the purchased supply power factor controller when the power on the Pretoria feeders reverses.

As failure of the potential supply from Ilgner House might cause incorrect regulation, voltage failure relays are used. These are plain contactor type relays with coils connected across the potential supply and with their contacts in the parallel operation pilot circuit. Thus, if one or both of these relays drops out, alarm is given and automatic control is interrupted in the same way as when the stations become separated.

Limit Switch Alarms.

In order to give indication of limit conditions of governor setting or excitation on any machine having been reached, alarm relays are provided. Their coils are arranged to be connected across the governor limit switches and across the rheostat limit switches. Operation of any limit switch thus closes the corresponding relay, one pole of which actuates a hooter (these contacts on all twelve relays are connected in parallel); the other pair on each relay is arranged to feed a particular lamp on the main alarm indicating board. When the hooter sounds, it is cut out by means of a double pole alarm switch, one of which is associated with each indicating lamp. One normally closed pole breaks the appropriate motor feed, so cutting out the alarm relay and silencing the hooter, while the other, which is normally open, gives an alternative feed to the lamp on the indicating board to maintain the indication of limit conditions.

In conclusion, the author wishes to thank the South African Iron and Steel Industrial Corporation Ltd. for some of the information given, and for their kind permission to publish this article and also to acknowledge the valuable assistance given by the client's engineer and the Electricity Supply Commission during the design of the scheme and the installation of the equipment.

An Electro-Acoustic Tester for Loudspeakers.

By E. P. FAIRBAIRN, B.Sc. (Eng.).,
G.E.C. Telephone Works, Coventry.

The article entitled "The Appraisement of Loudspeakers" which appeared in the G.E.C. Journal, Vol. VII, *No.* 4 *and Vol.* VIII, *No.* 2 *dealt in detail with the various factors which affect the quality of reproduction given by an electro-acoustic system. It was shown that, while many other considerations enter into the problem, the response curve of the loudspeaker is of fundamental importance, and the methods of plotting this curve were explained. From these it can be realized that the "point-by-point" method of measuring a response curve is both lengthy and laborious and, if a large number of curves is required, entails considerable expense. In this article the author describes a special recorder gear which has been developed to obtain response curves quickly and easily.*

SINCE the design of loudspeakers is still largely empirical, series of curves showing the effects of various changes in design are very useful, and the ability to take these quickly and easily, even at the expense of a certain loss of accuracy, justifies the cost of development of special recording gear. Such gear has been developed at the Telephone Works of the G.E.C. where it has been in use for a considerable time.

An explanatory diagram showing the principle of operation is given in fig. 1. A variable-frequency oscillator feeds the loudspeaker to be tested through a control unit which can be set to maintain automatically either a constant voltage across the loudspeaker speech coil or a constant current through it. The oscillator also adjusts a spot of light on the screen of the recorder to a position on the frequency axis corresponding to the frequency which is being fed to the loudspeaker. The sound emitted by the loudspeaker is picked up by a microphone and, after amplification and rectification, controls the position of the recording spot on the response axis. As the frequency is altered progressively over the audible range the spot traces out a curve, any point on which is a measure of the volume of sound emitted by the loudspeaker at the frequency corresponding to the point. Before describing this gear some points which influenced its design may be considered.

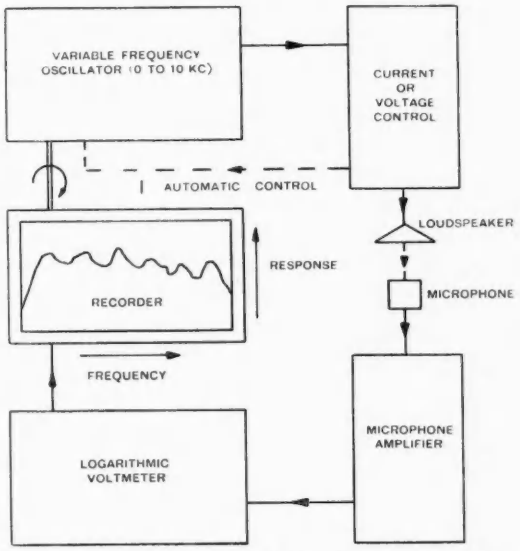


Fig. 1.—Explanatory diagram showing principle of operation.

EFFECT OF SOURCE.

The output stage which feeds a loudspeaker has, in general, either triode or pentode valves. From the point of view of the loudspeaker, the characteristics of the source are different in these two cases. When triode valves are used the source is of low impedance and for equal input voltages supplies approximately equal voltages across the loudspeaker coil at any frequency. When pentodes are used the source is of high impedance and for equal input voltages supplies approximately equal currents in the loudspeaker coil. In the first case, the current in the speech coil decreases when the impedance rises, which occurs at the higher frequencies because of the inductance of the coil, and at the main bass resonance because of the motional impedance of the loudspeaker as a whole. With constant voltage, therefore, the output decreases at the higher frequencies, while the bass resonance is either much reduced or entirely eliminated. For design purposes it is as well to know the worst, and to take curves with constant current in the speech coil, but the point should be borne in mind when examining the published response curves of some loudspeakers.

EFFECT OF ROOM.

Since the great majority of loudspeakers are used in living rooms it was decided that response

curves should be taken under the same conditions. As explained in a previous article[1], this necessitates using a warble tone for the oscillator, the warble being zero for the lowest and a maximum for the highest frequencies, and this feature has accordingly been incorporated. A room was already available, built and furnished as a standard living room and used for subjective listening tests. This room is now used also for taking response curves. Fig. 2 shows the room with a loudspeaker and microphone in position for a test.

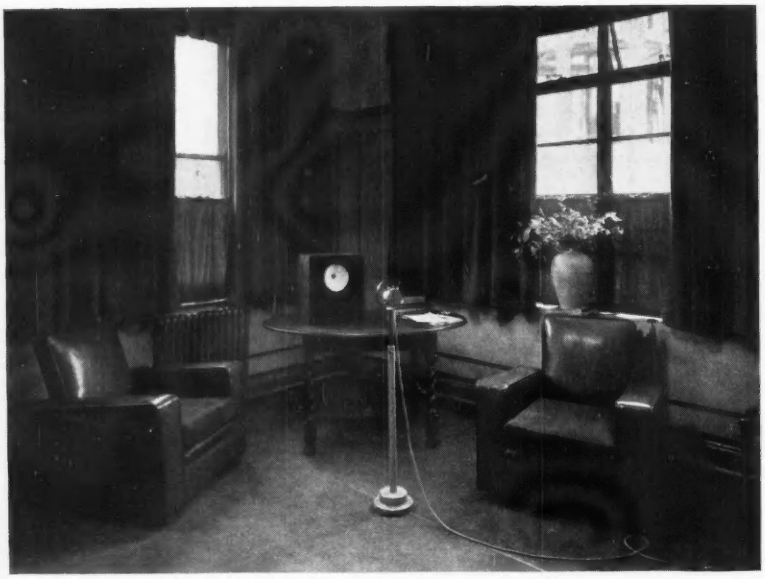


Fig. 2.—Loudspeaker under test in furnished room.

TYPE OF RECORD.

Finally, it was desirable that the records should conform to the recommendations of the Radio Manufacturers' Association, and that it should be possible to observe as well as record them, and if necessary, to concentrate on any small portion of the curve which might be of special interest. The record is therefore traced by a spot of light on a 10in. × 8in. ground glass screen, this being a standard photographic size. By replacing the ground glass by a sheet of bromide paper carried in a dark slide a photographic record may be obtained. A motor drive is used for the main tuning condenser of the oscillator, the curve being traced in 3 minutes.

DESCRIPTION OF THE EQUIPMENT.

A front view of the equipment is shown in fig. 3 and a rear view with the covers removed in fig. 4

1—The Appraisement of Loudspeakers, G.E.C. Journal, Vol. VII, No. 4 and Vol. VIII, No. 2.

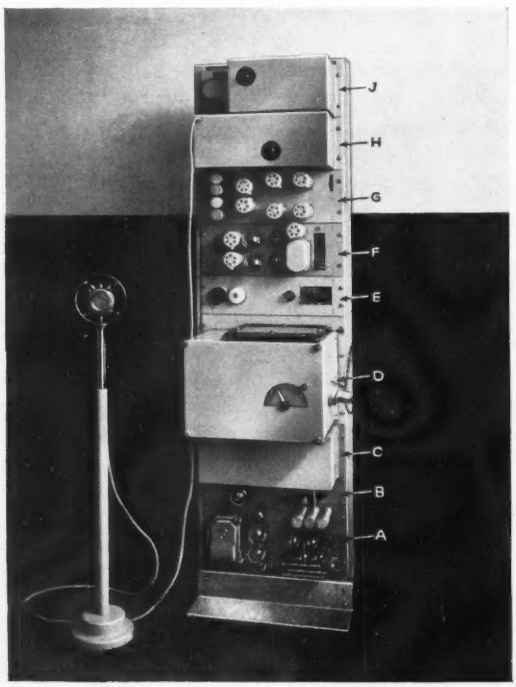


Fig. 3.—Electro-acoustic recorder, front view.

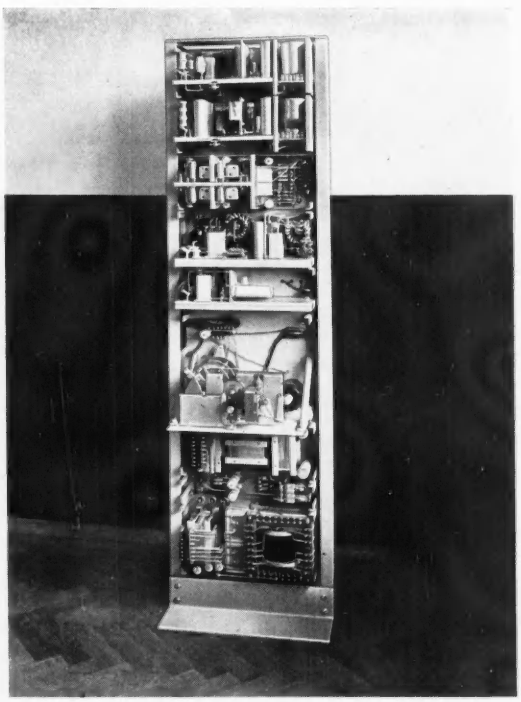


Fig. 4.—Rear view of recorder with covers removed.

Starting from the bottom the panels are as follows:

Panel (A) Power Supply.
Panel (B) H.T. Switching.
Panel (C) Decoupling.
Panel (D) Recording.
Panel (E) Control.
Panel (F) Oscillator L.F. Amplifier.
Panel (G) Oscillator.
Panel (H) Condenser Microphone Amplifier.
Panel (J) Auxiliary Microphone Amplifier.

With the exception of the two push-pull output valves of the oscillator L.F. amplifier, which have 4-volt directly heated filaments, all valves are of the 4-volt indirectly heated cathode type. The heaters of the first two valves of each microphone amplifier are supplied in series with rectified and smoothed A.C. from an 8-volt 2-amp. metal rectifier, all other filament supplies being 4-volts A.C. Power for the whole equipment is supplied from 230-volt 50 cycle mains, a common mains transformer being used. Four individual windings on this transformer are provided for the valve heaters on panels (F) to (J), a fifth for the filaments of the oscillator L.F. output valves, and others for the metal rectifier and for the H.T. rectifier heaters and anodes.

The H.T. is provided by two GU1 rectifiers in bi-phase. The rectified current passes through barretters to a load resistance which is adjusted to give the correct working current for the barretters. From the load resistance each panel is supplied *via* a separate choke and condenser decoupling and smoothing filter mounted on the decoupling panel. This arrangement has been found to give adequate smoothing, decoupling and freedom from the effects of mains fluctuations.

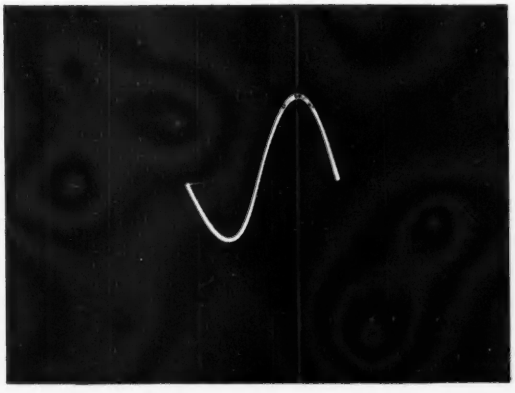


Fig. 5.—Wave form of oscillator.

DELAYED SWITCHING.

Since the GU1 valves are worked at their full output it is necessary to allow their heaters to warm up before taking the full load current from them, and this function is performed automatically by the H.T. switching circuit. This consists essentially of a condenser and resistance in series across the rectified H.T. circuit, with an Osglim lamp and relay in series across the condenser. On switching on, the condenser charges up slowly through the resistance until the striking voltage of the Osglim lamp is reached, when it discharges through the lamp and relay, operating the latter, which connects the full load to the rectifiers. The delay time is about 50 seconds.

OSCILLATOR CIRCUIT.

The oscillator is of the beat-frequency type,

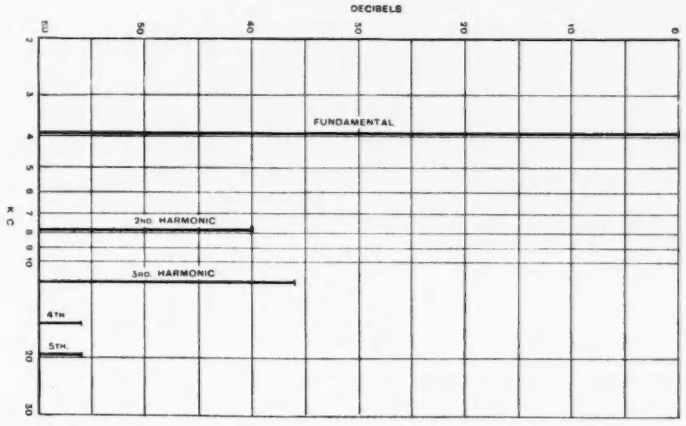


Fig. 6.—Harmonic content of oscillator output.

with dynatron oscillating valves, the fixed frequency being 125 kc and the variable 114–125 kc, giving a beat frequency range of 0–11,000 cycles/sec. Each oscillating circuit is loosely coupled to a buffer valve of the variable-mu type, the grid bias voltages of which are derived from the control panel. The variable-frequency buffer valve is connected in push-pull to the oscillator grids of a pair of heptode valves (MX40), *via* a 114–125 kc band-pass filter circuit, while the fixed frequency buffer valve is connected to the signal grids of the same heptodes in parallel *via* a circuit sharply tuned to 125 kc. The signal grid bias voltages of these valves are also derived from the control panel. By means of resistance potentiometers in these circuits the fixed frequency is adjusted to be a small fraction of the variable frequency and a balanced output is obtained. The arrangement gives freedom from harmonics in the audio-frequency range, and a small variation of output as the variable frequency is changed. There is also little coupling between the two oscillators, and beat frequencies of one or two cycles/sec. can be obtained. This feature is not important for the actual testing, where 50 cycles/sec. is about

the lowest frequency of interest, but if the two oscillators pull into synchronism over a range of say 10 cycles/sec. when the frequency zero is adjusted by the zero-beat method, the calibration may be out by that amount, giving a large percentage error on the low frequencies.

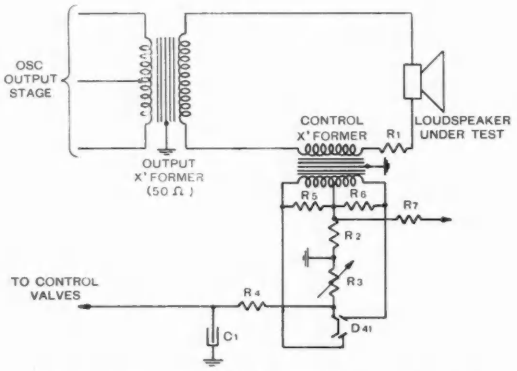


Fig. 7.—Circuit diagram of constant current oscillator.

The output of the heptode valves is resistance coupled through a low-pass filter to two L.F. amplifier valves in push-pull, which are in turn resistance coupled to the output valves (PX4). The output transformers are arranged to plug in, three being

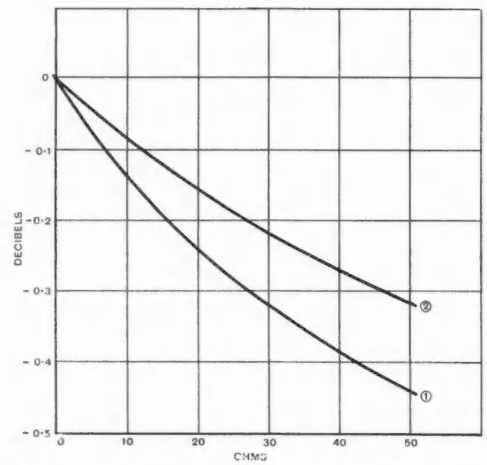


Fig. 8.—Automatic volume control regulation for two values of current.

provided, one to match 600 ohms for general purpose use, one to match 50 ohms for loudspeaker tests at constant current and one to match 2 ohms for loudspeaker tests at constant voltage.

The oscillogram in fig. 5 shows the excellent output waveform at about 12 cycles per second. The harmonic content at a higher frequency is represented in fig. 6.

CONTROL CIRCUIT.

The oscillator can be made to give practically a constant voltage across, and therefore a constant current in, a pure resistance at all frequencies in the audio range.

Since the impedance of a loudspeaker varies considerably over the frequency range a special arrangement is necessary to keep either the voltage or the current constant. Fig. 7 shows schematically the arrangement for the constant current case. The constant voltage circuit is similar to this circuit except that the resistance R1 is omitted, and a voltage transformer connected across the line is used in place of the current transformer shown. It can be seen that the circuit is the conventional one for providing automatic volume control, except that full wave rectification is used. The automatic volume control lead controls the grid bias voltage of the buffer and heptode valves, and the delay voltage is given by the drop across resistance R3 which is variable, and is adjusted until the desired current is obtained. Fig. 8, taken on a resistance load at 800 cycles/sec., shows the regulation obtained for two different values of current. It is evident that the method will also compensate for changes in output due to mains voltage fluctuations.

WARBLE CIRCUIT.

The circuit for providing the warble is shown diagrammatically in fig. 9 in which C1 is the tuning condenser of the variable frequency oscillator, C2 a small condenser mounted on the same shaft, and C3 the warble condenser rotated by a small motor at about 240 r.p.m. and having plates shaped to give a sinusoidal variation of capacity. With C1 at its

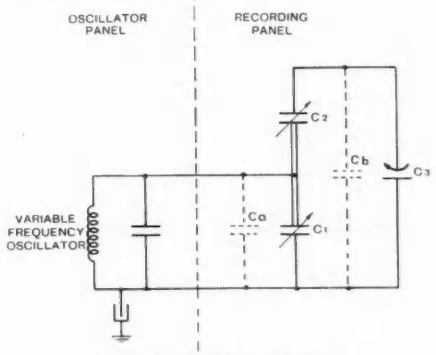


Fig. 9.—Warble circuit.

minimum position (zero frequency), C2 is also at its minimum and as it is carefully screened its plate-to-plate capacity is negligible and the rotation of condenser C3 does not alter the capacity across the tuned circuit. As C1 rotates (*i.e.*, as the beat frequency increases) the capacity of C2 also increases and with it the amount of warble given by C3. By suitable shaping of the plates of C2 any desired law can be obtained, and the stray capacities shown by Ca and Cb can easily be allowed for.

RECORDING SYSTEM.

The optical system used for recording is shown in fig. 10. The cam is fixed to the shaft of the main tuning condenser and rotates with it, tilting the plane mirror and providing the frequency scale, while the deflections of the galvanometer mirror which correspond to the sound output of the loudspeaker are at right angles, and provide the response scale. A measurement of oscillator frequency against angle of rotation of the condenser was first made and the cam designed from this to give a logarithmic frequency scale. This method eliminates all errors due to the shape of the main tuning condenser vanes and to stray capacities.

The sound output of the loudspeaker is picked up by a condenser microphone which is connected to the condenser microphone amplifier by a low-capacity cable. This amplifier is resistance-capacity coupled and incorporates a network to compensate for the characteristic of the microphone. The output of the amplifier is rectified by a diode and the D.C. voltage developed across the load resistance R1 (fig. 11) is applied to the grid of a triode *via* the high resistance R2 to cause a grid current to flow. Resistances R4 and R5 are chosen so that no current flows in the galvanometer initially. This circuit, which is due to E. L. Payne and J. G. Story[2], gives a logarithmic relation between the applied A.C. volts and the current in the galvanometer over a considerable voltage range, so that the "response" scale can be calibrated in decibels.

The accuracy of the scale obtained may be seen from the records reproduced in fig. 12, which shows different curves for the same loudspeaker, taken under conditions explained later. The zero line is the same in all three figures.

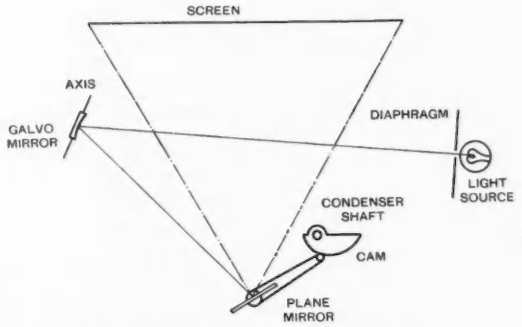


Fig. 10.—Optical system for recording.

These three curves were traced by hand while the curves of fig. 13 were recorded photographically In practice, the hand tracing method has so far proved the more popular. The main advantages are that the curve can be checked at once by running over it again and seeing that the spot traverses the same path, and that extraneous noise, such as the slamming of a door, can be neglected, whereas on a photographic record a false peak is shown.

The auxiliary microphone amplifier is generally similar to the condenser microphone amplifier except that no correction circuit or microphone polarizing circuit is provided, and the input to it is by a transformer of the plug-in type. Either amplifier may be connected to the recording circuit so that records may be made using microphones of types other than the normally used condenser microphone.

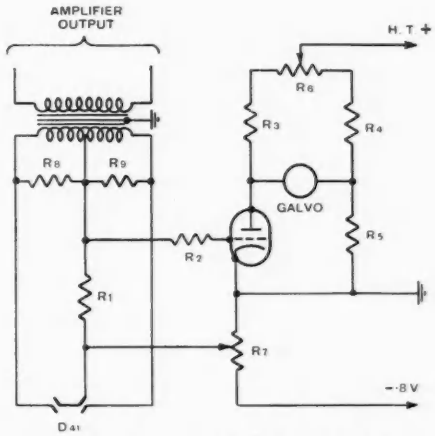


Fig. 11.—Output circuit of amplifier.

RESULTS OBTAINED.

Fig. 12 shows three records of the same loudspeaker in the same cabinet, taken under different conditions. In all cases the microphone was on the axis of the loudspeaker and at a distance of three feet. In curve (a) the current in the speech coil was kept constant at 100 mA. but the warble tone was not used. In curve (b) the current was again kept constant at 100 mA. but a warble tone was used. This is the standard method of testing loudspeakers. In curve (c) the voltage across the speaker was kept constant and adjusted to give approximately the same output at 400 cycles, the warble tone being used.

The difference between curves (a) and (b) shows the effect of the warble tone. Below about 150 cycles/secs. and above about 3,000 cycles/sec. the curves are identical. Since the warble tone is arranged to be inappreciable below 100 cycles/sec. this coincidence is to be expected at the lower end. At the upper end, the concentration of the sound on the axis, the greater absorption of the room furnishings and the finite size of the microphone probably account for the smoothness of the curve, even when no warble is employed. The value of the

2.—Wireless Engineer, November 1935.

warble tone is well shown in the middle range of frequencies, even at the comparatively close spacing of microphone and loudspeaker used in this test. With greater spacing or in more resonant surroundings the smoothing effect is even more marked, as loudspeaker. In the middle range of frequencies, the curves coincide, but for the constant voltage case the main bass resonance has disappeared owing to the high impedance of the speech coil at this point, and the higher frequencies have been

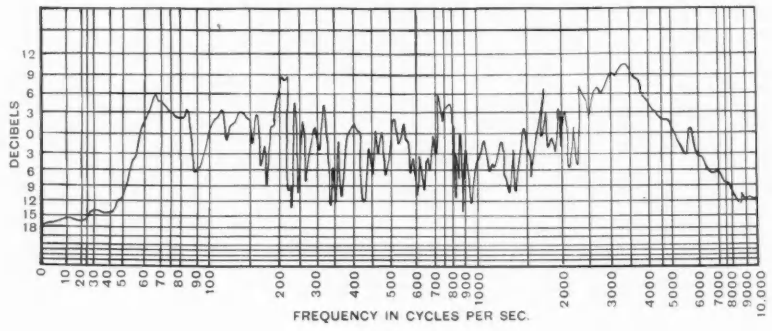


Fig. 12 (a).

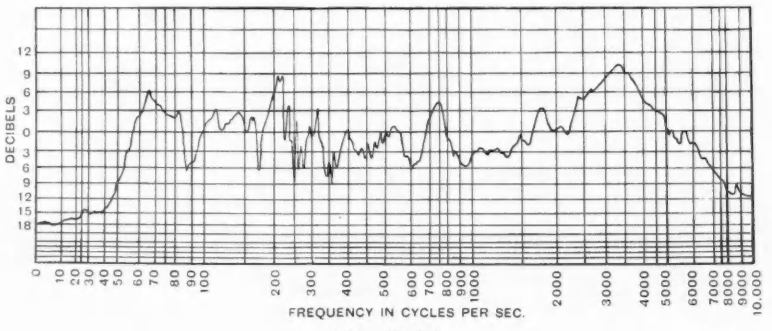


Fig. 12 (b).

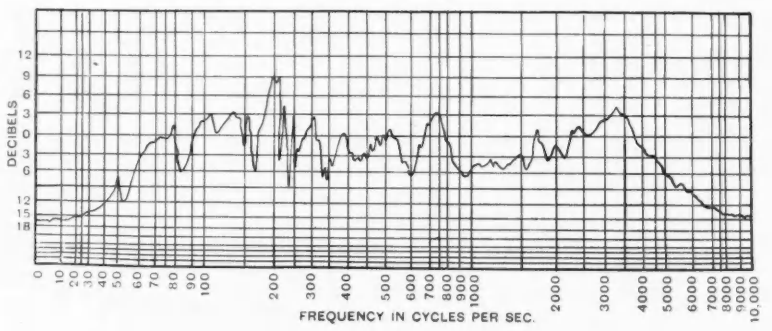


Fig. 12 (c).

Figs. 12 (a), 12 (b) and 12 (c).—Loudspeaker response curves traced by hand.

can be seen from fig. 13 which was taken with a spacing of six feet between the microphone and loudspeaker and in a room with less damping. In this case the gain of the microphone amplifier was altered between recordings in order to avoid confusion

The difference between curves (b) and (c) in fig. 12 illustrates the effect of the source on the attenuated owing to the increase of impedance of the speech coil with frequency. The curves were taken to illustrate the foregoing points, and are not claimed to be representative of loudspeakers fitted in modern sets.

The equipment has been found useful for a variety of measurements. Polar curves of loud-

speakers and overall curves of L.F. amplifiers, and their associated loudspeakers, are obvious examples.

By modulating a signal generator at a constant voltage, overall fidelity curves of complete radio sets have been made, and the effects of fidelity and variable selectivity controls demonstrated.

The ease and speed of operation enable frequent checks to be made on production and so eliminate a common cause of trouble which has been obtained in the past.

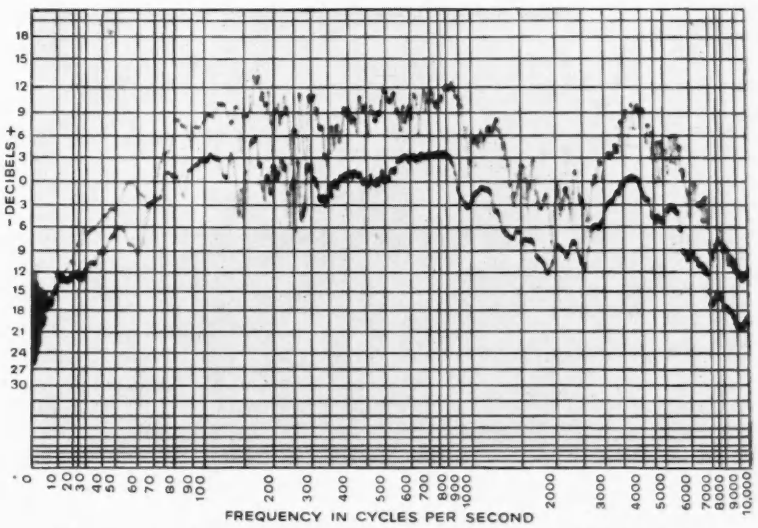
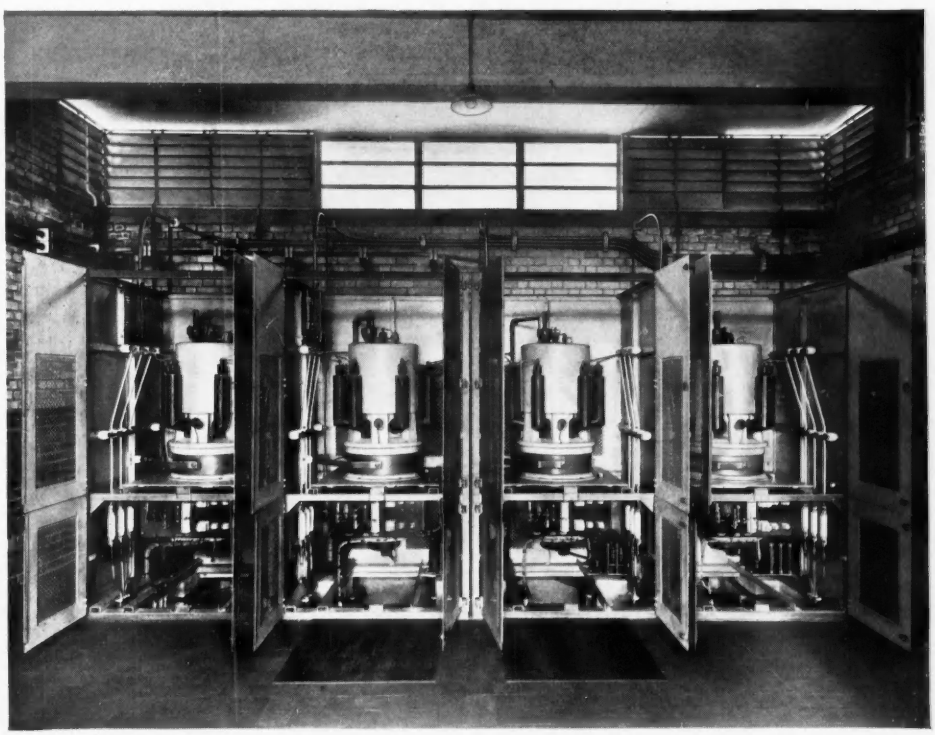


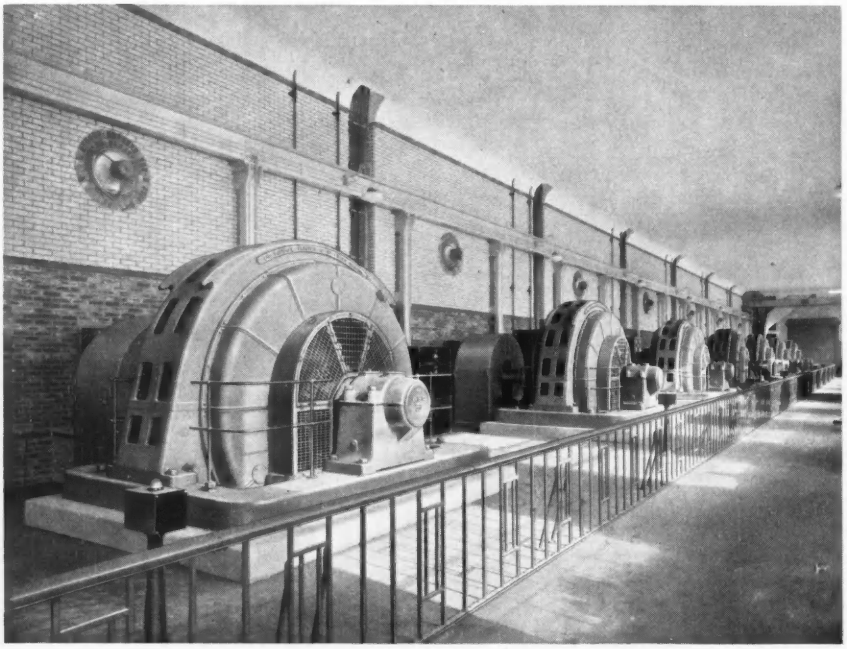
Fig. 13.—Loudspeaker response curves recorded photographically.

Pumpless Air-cooled Steelclad Mercury Arc Rectifiers for London Transport.



Two 375 kW (normal rating 500 kW) 600 volts D.C., twin cylinder, pumpless, air-cooled, steelclad mercury arc rectifiers installed in the Highams Hill substation of London Transport. A total of 23 similar cylinders are now operating on the Board's system.

The Electrical Control of Paper Making Machinery.



By W. J. MASON, A.I.E.E.,

Engineering Dept., of
The General Electric Co., Ltd.

Fig. 1.—Seven 2,500 h.p. slipring induction motors, 6,600 volts, 3-phase, 50 cycles, 250 r.p.m. driving process equipment in the Kemsley Paper Mill of Edward Lloyd, Ltd.

THERE has been in recent years a very considerable increase in the demand for paper of all classes, particularly for newsprint. These demands are to-day being met by the use of electric drives, which, in conjunction with the great advance made in the technical control of paper making machines, enable higher operating speeds to be used without impairing the quality of the produced paper.

It is proposed in this article to discuss the problems involved in the driving and control of paper making machinery and to describe the system successfully employed by the G.E.C. In this connection it is intended, in an early issue of the *G.E.C. Journal* to give a description of some recent important installations in which this system of driving is embodied.

In the past, paper making machines were driven by means of belts or ropes running on adjustable pulleys (see fig. 3). With the increased operating speeds which were required, involving an increase in the power which had to be transmitted, the adjustable belt drive became unreliable. Many alternative methods of driving were tried until it became established that the most reliable form of drive was that employing individual electric motors driving each section of the paper machine, the motors being automatically controlled as regards speed.

In order fully to appreciate the problems peculiar to the paper machine drive it will be of advantage to outline briefly the various processes involved in the manufacture of paper.

PAPER MAKING PROCESSES.

Pulp

The raw material used in the manufacture of paper is cellulose with the addition of fillers, dye stuffs and chemicals. The cellulose is obtained chiefly from wood, rags and esparto grass, the main source being wood. This is prepared in two ways; one involves the cooking of wood chips in "digesters" containing acid and steam, a process which separates the cellulose fibres from the unwanted resins. In the other process, the wood is ground into "flour" in mills individually driven by electric motors, similar to those shown in fig. 1. Rags and esparto grass also undergo a steam cooking process which separates the fibres from all foreign matter.

The pulp obtained from these processes is next mixed with water and broken down into a porridge-like mixture which is taken to machines called "beaters." These consist of a trough which holds

the mixture, in which revolves a roll fitted with bars spaced axially on its surface. The mixture passes between the roll and a bedplate on which are mounted similar bars. As the mixture passes through, it receives a brushing action which changes the nature of the cellulose fibres. A general view of electrically driven beaters is given in figs. 2 and 4. The beating process profoundly affects the characteristics of the finished paper which are dependent on the

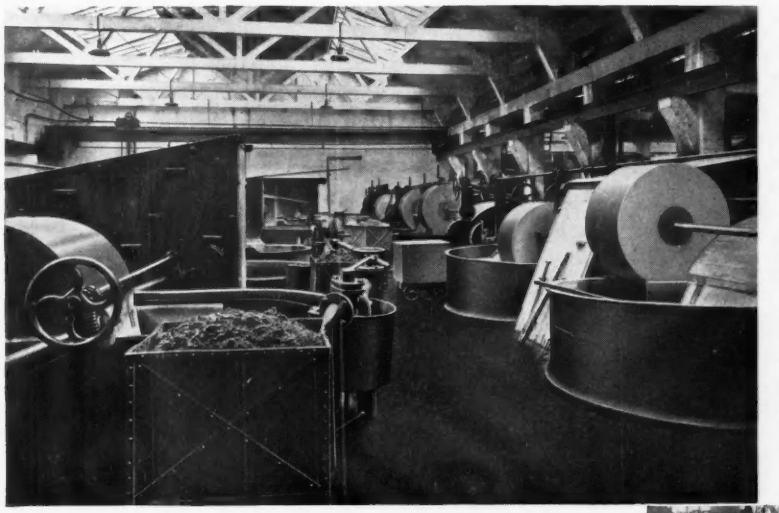


Fig. 2.—A group of beaters and breakers belt driven by 75 h.p. motors.

beating time and the pressure of the roll on the bedplate. It may be mentioned that the widely divergent characteristics of blotting paper and grease-proof paper, both of which are made from identical raw materials, are produced solely by alterations in the beating time and pressure of the roll.

After beating, the mixture, or "stock" as it now is called, is passed through refiners, fig. 5, which further separate the fibres. More water is added and, finally, the stock is passed through fine slit screens to remove any lumps. The stock is then ready for the paper making machine.

Paper Making Machine.

A diagrammatic representation of a paper machine is shown in fig. 6. The function of the machine is to abstract the water from the stock and to form the latter into a sheet. This is done in three stages, the first of which comprises the "couch" section of the machine, consisting of an endless wire mesh band of fine gauge supported on rolls to form a flat surface. The stock flows on to this band which carries it along in a steady stream. Water drains from the stock through the wire mesh, while along the band at a distance of about two thirds of its length are mounted a number of suction boxes which remove more of the water in the stock. Finally the band passes over a suction roll which also usually functions as the driving roll of this section of the machine.

The sheet can now be recognised as paper although it is still wet, having a moisture content of 80 per cent. It is nevertheless capable of supporting itself over a short length. The sheet now enters the second stage of manufacture in which the moisture content of the sheet is reduced to 70 per cent by squeezing between rolls. As no further water can be removed by mechanical means without damaging the sheet, the remaining and third stage of the process is therefore the removal of the residual moisture by means of dryers and calenders. The dryers are steam - heated cylinders over which the sheet passes, reducing the moisture to about 8 per cent. The calenders consist of a vertical stack of 8 to 10 chilled cast iron rolls, the paper being fed to the roll at the top of the stack, passing down between each pair of rolls and being subjected to increasing pressure in order to impart a polish to both sides of the paper. The pressure

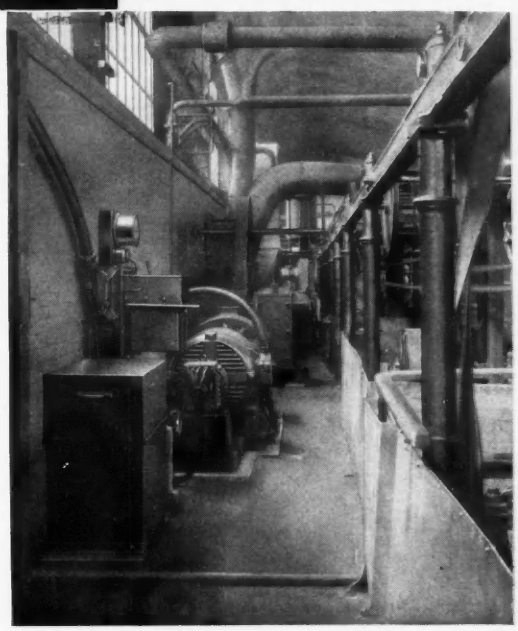


Fig. 3.—Paper mill drive showing Ward-Leonard motor-generator set, driving motor and control gear.

between the nip of the bottom rollers is of the order of 250 lbs. per inch width. Finally, the paper is wound into reels about 4 ft. in diameter.

Further operations, such as super-calendering as shown in figs. 7 and 8, trimming, or cutting into sheets

are necessary for certain commercial requirements but these processes are not performed by the paper machine.

It will thus be realised that the chief function of a paper making machine is that of de-watering. In actual fact, for each ton of paper produced on the reels, over 150 tons of water have to be removed, requiring 80 kWH of power for driving purposes, 4 tons of steam for heating and about 40 tons of air to carry away the evaporated water.

DRIVING REQUIREMENTS.

From the preceding description of the paper-making machine, it is clear that the process is continuous, *i.e.*, there is no break between the various stages. The driving of the various sections of the machine would present little difficulty were it not for the all-important fact that the sheet changes in length as it passes through the machine. The pressure of the rolls causes an elongation of the sheet which more than counteracts the shrinking caused by the removal of moisture. The actual increase in length amounts to between 5 and 8 per cent, the increase all taking place at the couch and presses and the shrinking at the dryers. It will thus be seen that the unit drives of each of the various sections of the machine must be driven at slightly different speeds in order to accommodate the changes in the length of the sheet. In the modern unit electric drive this variation in the speeds of the different sections is performed automatically, the equipment being provided with what is known as "automatic draw control."

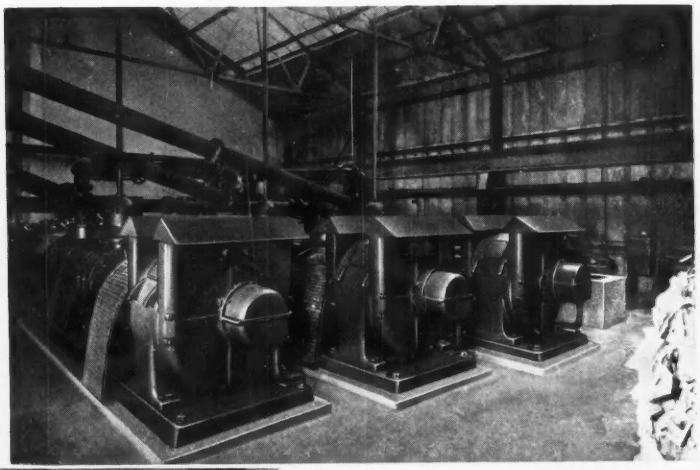


Fig. 5.—Three 100 h.p. slipring induction motors direct coupled to refiners through flexible couplings.

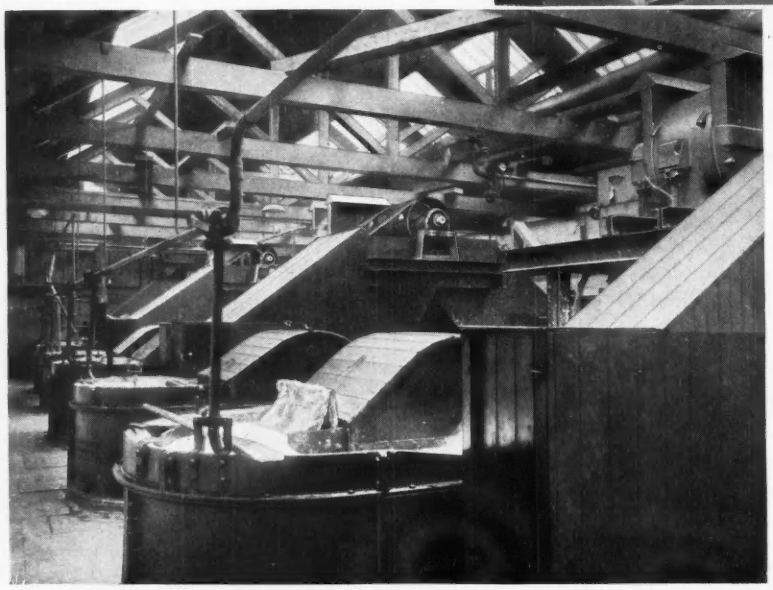


Fig. 4.—120 h.p., 360 r.p.m. motors driving beaters through belts.

The modern unit electric drive should possess the following features:

1. Automatic draw control which is independent of the power being transmitted by the driving motors.
2. Means for readily adjusting the draw between sections of the machine without interfering with production.
3. When once adjusted the draw must remain constant for load and temperature variations throughout the speed range.
4. Rapid corrective response to any change in conditions.
5. The speed of the drive as a whole must be adjustable over a range to suit particular requirements.
6. A crawling speed of about 60ft. per min. for

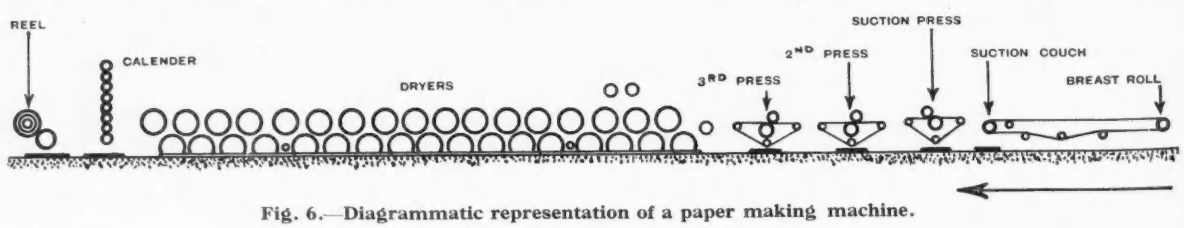


Fig. 6.—Diagrammatic representation of a paper making machine.

examination of machine wire and felts.
7. Ability to run for long periods without maintenance.
8. Suitability for working under unfavourable conditions of temperature and humidity.

The unit drive developed by the G.E.C. comprises a motor-generator or booster set (depending on the system of electric supply to the mill) with D.C. motors driving through gearing each section of the paper machine, each section having an automatic draw regulating mechanism and control panel as shown in the simplified diagram of the unit drive, fig. 9.

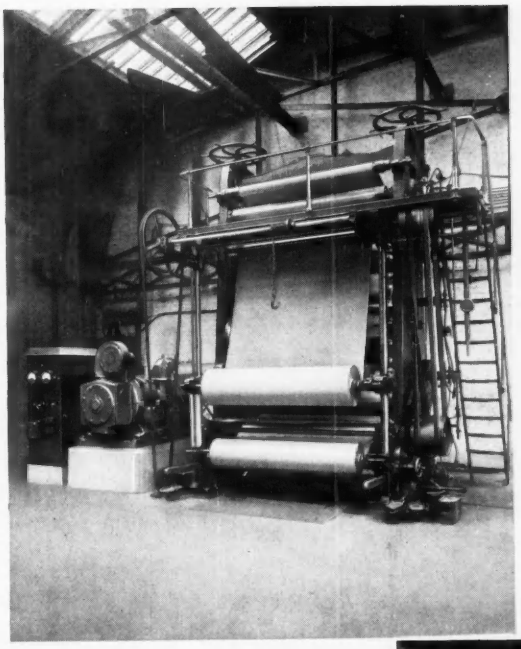


Fig. 7.—Calender drive showing totally enclosed D.C. motor and control pillar on left.

The principal features of this drive are discussed in the following sections of this article.

DRAW REGULATOR.

It will have been gathered that the paper substance passing through the machine is of a very fragile nature and the necessity for accurate speed maintenance of the various sections of the machine is of paramount importance if the paper substance is not to be strained or broken. This is particularly essential in the case of high speed machines having a paper speed of nearly 1,500 ft. per min. In its wet state, after leaving the couch, standard newsprint paper has a safe tensile strength of approximately 0·06 lbs. per inch width and the tension produced by its own weight is about 0·04 lbs. per inch. Thus, the margin of safety is extremely small and it is found in practice that the speed of the paper must not vary by more than 0·05 per cent. between sections.

The couch is the most exacting section of the machine as regards speed, and any straining of the paper substance at this point will affect the strength of the finished product. In the finished state, paper of the type described is 3/1000in. thick and has a tensile strength of 12 lbs. per in. width, the strength of the sheet reaching this value progressively as the moisture is removed during the passage of the sheet through the machine.

In order to obtain the required accuracy of speed control the draw regulator must be extremely sensitive and function for minute changes in the speed of the driving motor. The principal on which the draw regulator operates is that of an electric differential in which the angular velocity of each section motor is matched against the velocity of an independent master motor-alternator which in turn has a speed proportional to the supply voltage. Any difference in the velocity of a section motor from that of the master set is corrected by a regulator operating in the field of the section motor.

The section motors themselves must be designed to give a rapid response to the action of the regulator, necessitating the use of a motor having small time constants. A curve showing the time constants of a typical D.C. motor designed for driving paper machines is given in fig. 10. As the regulator cannot anticipate a change in speed of the

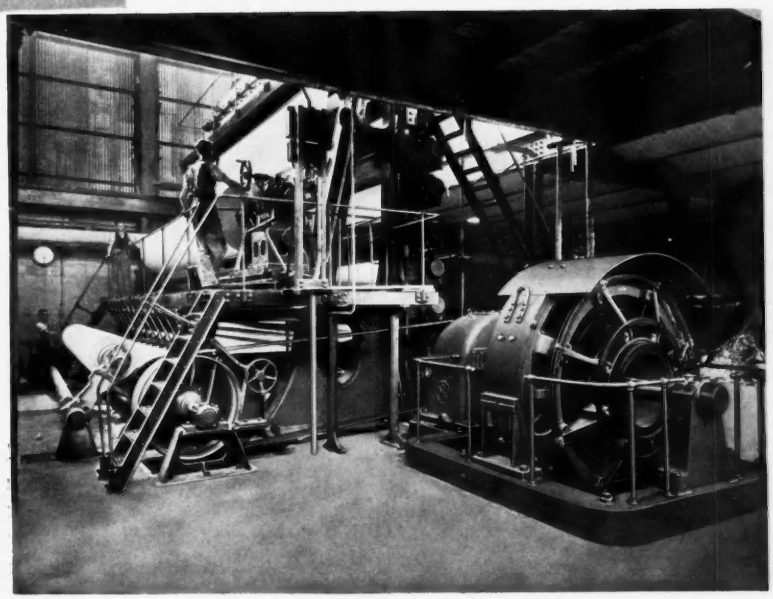


Fig. 8.—250/500 h.p. D.C. motor, 225/562 r.p.m. driving a super calender.

section motor, it is obvious that the armature of the latter must be displaced angularly before the regulator can function. The use of a sensitive regulator, the moving parts of which have small mass, operate in roller bearings and are fitted with rolling contacts, reduces "sticktion" to a minimum and a very small actuating force is required. Owing to the differential action, the movement of the regulator continues until the motor responds.

An anti-hunting device is provided on each draw regulator as, without it, under certain conditions it would be possible for the natural period of oscillation of the paper machine sections to coincide with those of the regulators. In order to overcome any possibility of resonance the anti-hunting device on each regulator is adjustable over a wide range and can be set on site.

The load characteristics of the machine sections vary, a fact which has to be considered in relation to the design of the draw-regulator. In a modern 3-roll paper machine, for instance, the inertia of the rolls, W.R.^{2}, varies from 55 ton ft.^{2} at the couch and presses to 3,000 ton ft.^{2} at the dryers and calender, whereas the reel has an inertia of only ·18 to ·22 ton ft.^{2} All these sections have to function synchronously, otherwise variations of a greater magnitude than is permissible may arise due to the coincidence of the disturbing force.

Finally, it may be stated that the section motors and their regulators are not unlike synchronous motors in their behaviour. With an increase in load, the armature of the motor is displaced angularly in a reverse direction, by a sufficient amount to cause the draw regulator to operate in a corrective direction. Unlike a synchronous motor, however, the angular displacement is not an inherent feature of the motor and, to a certain extent, can be controlled by the motor designer. Obviously, for a paper machine drive this angular displacement should have a low value, as in the form of draw control employing differential principle, any disturbance to the draw cannot be corrected, but passes through the machine in the form of a wave or ripple, travelling at the paper speed and having an amplitude depending on the amount of angular displacement.

Under certain conditions, the ripple starting at one section may coincide with a ripple starting at the preceding section, but providing the angular displacement of the section motor is taken into consideration as described, little trouble will be caused.

DRAW ADJUSTMENT.

To enable the draw to be adjusted, infinitely variable speed gear is provided between the motor and the section transmitter. This gear takes the form of a small cone pulley drive and gives a draw variation of about ±10 per cent, the belt actuating gear being of the remote control type. A draw indicator showing the position of the belt and pulleys is provided at the control point. The standard arrangement is to mount the draw regulator some distance from the drive (usually on the switch panels) so that it operates under the most favourable conditions, outside the humid atmosphere which normally surrounds the machine.

It will be clear that this form of draw regulator and its adjustment meets all the requirements specified at the beginning of this description.

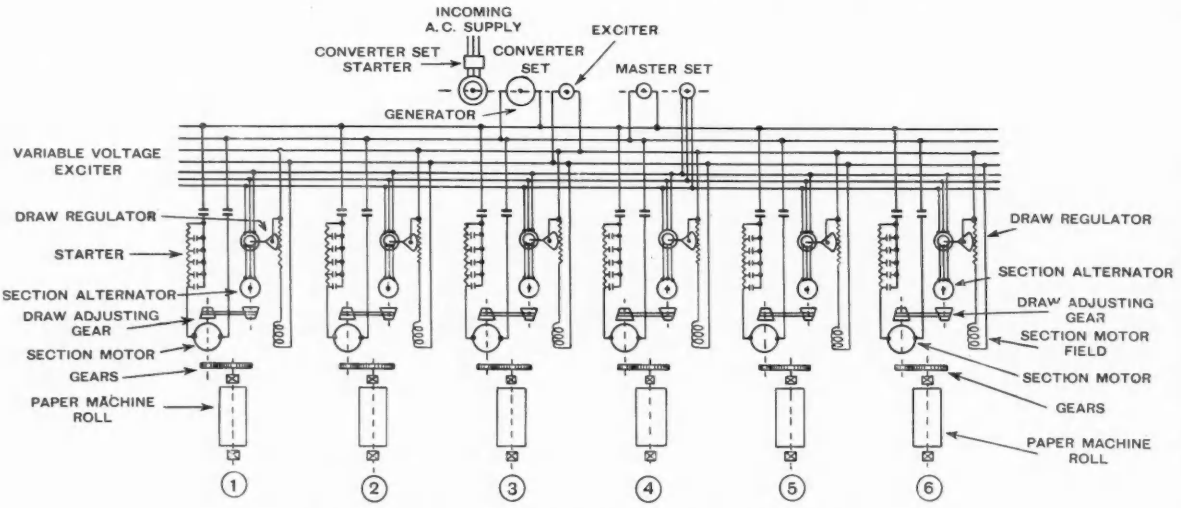


Fig. 9.—Schematic diagram of connections of unit drive.

CRAWLING SPEEDS.

It is necessary periodically to examine what is known as the machine clothing (*i.e.*, couch wire, press and drier felts) and for this purpose it is

desirable to be able to run any section of the paper machine at slow speeds. A suitable speed is 60 ft. per min. and is obtained either by inserting resistance in series with the section motor armatures or by the use of a small auxiliary low voltage generator, supplying current to the section motors. This generator may form part of the main converting set or may be driven by a separate motor. In the latter case the set is automatically controlled from the section control panels.

Normally, when all sections of the paper machine are running at normal speed, the crawling speed set is shut down, but immediately a section motor is stopped, the crawling speed set starts up so that the low voltage supply is immediately available. While this set is of comparatively small capacity it must have a current rating sufficient to deal with the starting torque of either the driers or calender.

SPEED REGULATOR.

A speed regulator is desirable on all paper machine drives, as all sources of electric supply are subject to variations. While with modern electric supplies these variations are comparatively small, they are nevertheless sufficient to cause an alteration in the speed of the whole drive involving an increase or decrease in the weight of the paper produced. The installation of an accurate speed regulator, which automatically compensates for any alternations in the supply, thus enables a more uniform paper to be produced. In the case of high speed paper making machines (*i.e.*, running at 1,000 ft. per min. and over) variations in the power supply to the drives will cause variations in the paper due to the difference in the inertia of the individual sections. Those sections having a small inertia will react to the change in voltage more quickly than those with a large inertia, thereby causing a series of waves or ripples in the paper, which, while similar to those previously mentioned, are more objectionable, as instead of producing one or two isolated ripples at irregular intervals there would be a series of ripples. In most paper machines the couch and the three presses have practically equal values of inertia, so that in the event of a variation in the supply, four ripples would be formed equally spaced along the paper at intervals representing a fraction of a second.

These ripples travel between the dryers and calenders at over 1,000 ft. per minute and as these sections have a larger inertia, thus taking longer to react to the change in voltage, certain critical ripples will arise which may result in breaking the paper. It will therefore be seen that for high speed paper machines a speed regulator is essential. A full description of a speed regulator which has been developed for a variable speed unit paper machine drive will be given in an early issue of the *G.E.C. Journal*.

STARTING TORQUE.

The starting torque of the various sections of the paper making machine vary approximately in the ratio of 1 : 20; the couch presses have the lower values and the dryers and calenders the higher values. This wide divergence of starting torque considerably affects the design of the motors, reduction gears, shafts and couplings of the dryers and calenders and in these sections the starting torque is the limiting factor in determining the size of the motor. As the calculation of this torque depends on a number of features which cannot with any certainty be ascertained beforehand, a liberal allowance is necessary in determining the size of the crawling speed set where this is used, or in the rating of the resistances where these are employed to obtain the lower speed.

POWER REQUIREMENTS.

The paper machine will give a constant output

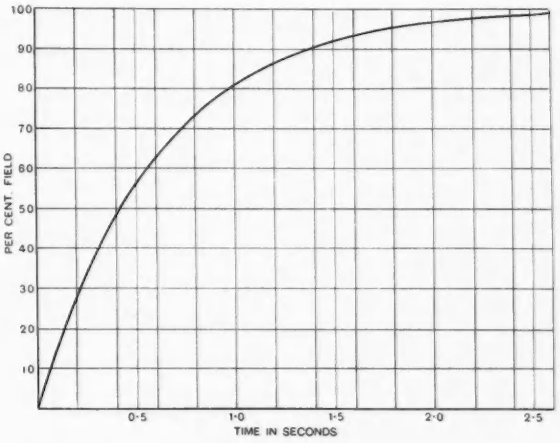


Fig. 10.—Curve showing the time constants of a typical D.C. motor designed for driving paper machines.

of paper at all speeds, but at high speeds the paper produced will be thin and, at low speeds, thick. The actual output of the machine is limited by the capacity of the drying cylinders to evaporate the surplus moisture. The paper machine has the peculiarity that the power required to drive it is influenced only to a small extent by the paper produced, 75 per cent of the power absorbed being required to overcome the machine friction and, in the case of high speed machines, friction due to windage.

A typical set of curves showing the average power required at the various sections of the machine is shown in fig. 11. The lower curve shows the power required to drive the sections with no paper passing through the machine. With paper passing through the machine, the couch requires the greatest increase in power due to the extra friction which

occurs between the wire band and the tops of the suction boxes when these are sealed by the paper on the wire. It should be mentioned that the values given in the curves are for normal running powers and allowance must be made in the rating of the motors to cover the falling off in the efficiency of the machine clothing, necessitating an increased vacuum in the suction boxes and rolls to obtain the same degree of water removal.

An increase in the torque of all sections is apparent at low speeds and is chiefly due to bearing friction increasing at low journal velocities. With the older types of machine, bearings were lubricated by means of a collar fixed to the journal which dipped into the oil well. At low speeds, however, the oil runs off the collar before it is delivered to the distributor in the top half of the bearing. Modern machines are provided with a pressure system of lubrication which is independent of the machine speed, and roller bearings are now extensively used on felt rolls which overcome the lubrication difficulties at low journal speeds.

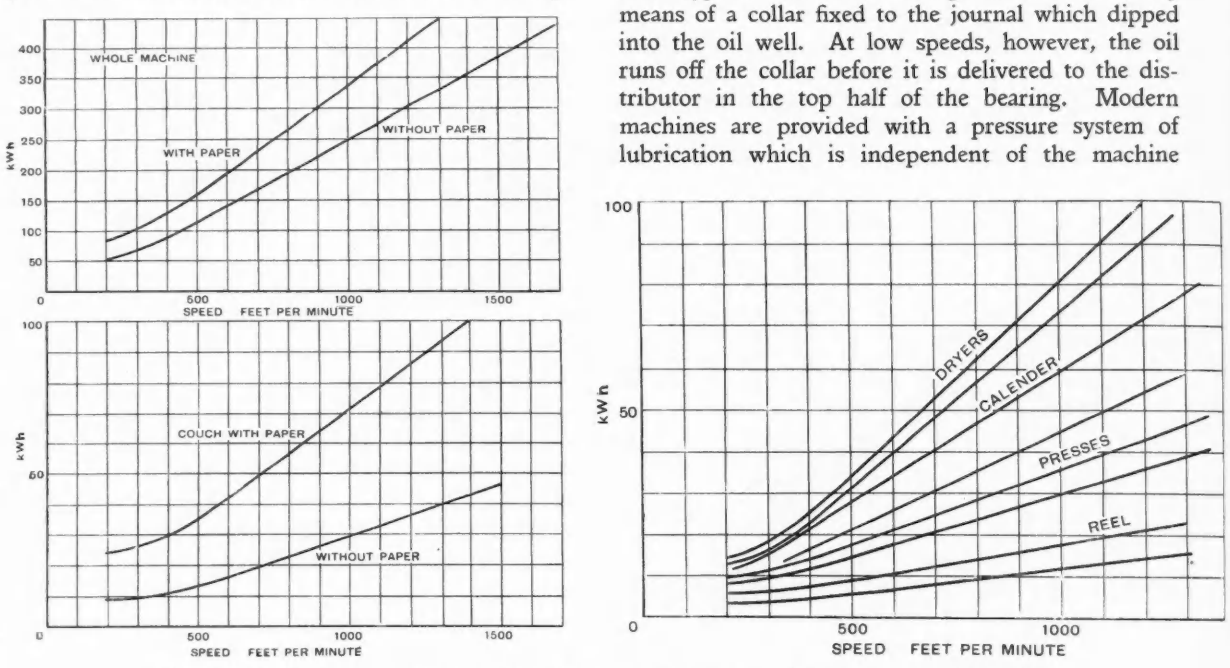


Fig. 11.—Typical curves showing the average power required at the various sections of a paper making machine.

Operating Theatre at Swansea Hospital, showing one of the new lighting fittings.

Shadowless Operating-Theatre Lighting Unit.

A new system of light distribution is embodied in the latest shadowless lighting unit for use in the operating theatres of hospitals The optical system enables approximately 90 per cent of the lamp flux to be redistributed usefully on the working area, giving the high average intensity of 650 foot-candles over a patch 12 ins. diameter and 3 ft. vertically below the unit.

The resultant beam takes the form of two independent hollow cones, the outer of which ensures a maximum of shadowless illumination, while the inner provides good cavity illumination.

A 150-watt standard lamp is used as the source of illumination, and an emergency lighting system is also provided, and comprises three 60-watt lamps, giving substantially the same light distribution.

Technical Literature.

A DIGEST OF RECENT BOOKS, ARTICLES AND PAPERS BY MEMBERS OF THE STAFF OF THE GENERAL ELECTRIC CO., LTD., AND ITS ASSOCIATED COMPANIES.

APPARATUS USED FOR HIGH POWER SWITCHGEAR TESTING.

By J. S. Cliff (Witton Engineering Works).

Jour. I.E.E., June, 1937.

The paper deals with the equipment and construction of a modern high-power testing laboratory capable of testing circuit breakers of ratings up to 1,500,000 kVA at voltages up to 132 kV. General details of the power circuits are given, including the generator, super-excitation system, load and power factor control, step-up and step-down transformers, and switchgear.

The metering and instrument equipments are also described, particulars being given of both low and high frequency oscillographs and their associated components.

*A NEW APPROACH TO THE PROBLEM OF TONE REPRODUCTION.

By R. G. Hopkinson (G.E.C. Research Laboratories).

Royal Photographic Soc. J., 77., Sept., 1937.

The fundamental theories upon which is based the problem of tone reproduction are considered. These considerations have been applied in the present work to the problems of photographic reproduction but they apply with equal validity to other problems, such as the determination of the characteristics of correct reproduction by television images or by projected cinematograph images.

*THE EDDY CURRENT HEATING OF COMPOSITE CYLINDRICAL SYSTEMS.

By D. A. Wright (G.E.C. Research Laboratories).

Phil. Mag. 24, p. 1, Jan., 1937.

Deals with the problem of whether the method of eddy current heating commonly in use for degassing the valve electrodes and for removing volatile impurities could be adapted to the production of valves having metal envelopes. This paper considers theoretically the eddy current heating of such composite systems and applies the theory to one or two systems of practical interest. Experiments which confirm the conclusions in the case of one of these systems are described.

*TELEVISION IMAGES. AN ANALYSIS OF THEIR ESSENTIAL QUALITIES.

By L. C. Jesty and G. T. Winch (G.E.C. Research Laboratories).

Trans. I.E.S., 2, August, 1937.

This paper deals mainly with the practical limitations to the realisation of the ideal picture imposed by the characteristics of the television system. Picture contrast, brightness, definition, size, presentation colour or tint and flicker are dealt with. New and accurate methods of measuring these characteristics are described and results given.

*SECONDARY-ELECTRON EMISSION FROM COMPLEX SURFACES.

By L. R. G. Treloar (The M.O. Valve Co., Ltd).

Proc. Phys. Soc. 49, p. 392, July 1st, 1937.

The secondary emission of metals, on whose surfaces foreign substances (*e.g.*, electropositive metals) have been deposited to various thicknesses up to a few atomic layers, has been studied.

This article is reprinted on page 254 of this issue of the G.E.C. Journal.

*THE EFFECTS OF TEMPERATURE ON THE INTENSITY OF FLUORESCENCE OF SOME IMPURITY SOLIDS.

By J. T. Randall (G.E.C. Research Laboratories).

Proc. Phys. Soc. "Report of Conference on the Conduction of Electricity in Solids." Vol. 49, No. 274, 31st August, 1937.

Investigation shows that for all the substances examined there is a critical temperature above which the fluorescence intensity always falls fairly rapidly and uniformly. The various results are also discussed in detail.

GASES AND METALS.

By C. J. Smithells (G.E.C. Research Laboratories).

Published by Chapman & Hall, 1937.

The book is divided into three sections dealing respectively with the Adsorption of gases on metal surfaces, the Diffusion of gases through metals, and the Solution of gases in metals. In each case the fundamental laws controlling the process are discussed, and quantitative data for the various gas-metal systems that have been investigated are given. Emphasis is laid on the close connection which exists between these three main types of equilibria, and this is brought out only when the work in all branches of physical chemistry is considered as a whole.

The author has made no attempt to deal with the practical application of these principles to metallurgical processes ; the aim has been rather to define the fundamental principles, and collect the available data relating to gas-metal equilibria in an accessible form, which should assist those who have practical problems to solve.

*A limited number of reprints is available ; copies may be obtained on application to the Editor, G.E.C. Journal, Witton Engineering Works, Birmingham, 6.

COAL WASHING PLANT

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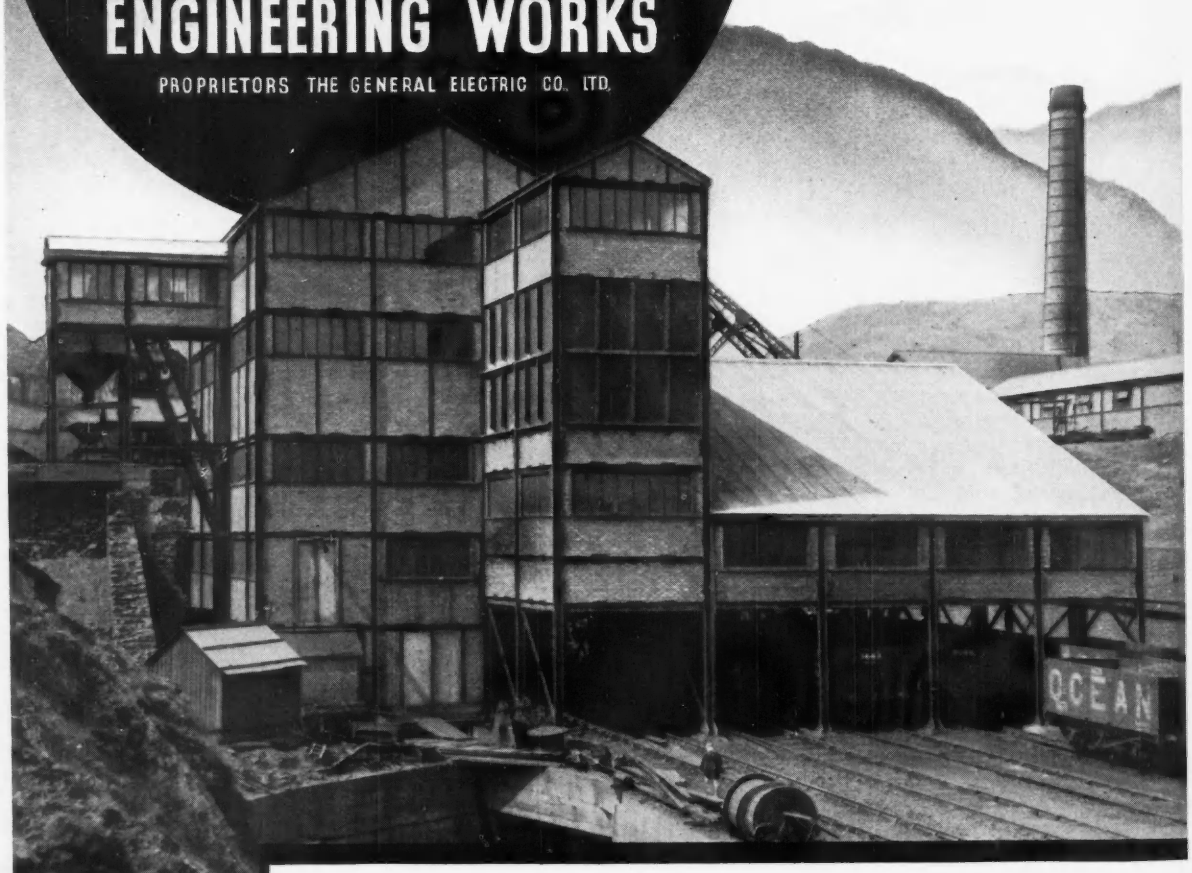

This building houses a coal washing plant, capable of dealing with 180 tons of 6″ × 0″ raw coal an hour, which was recently put into service at the Cwmparc colliery of The Ocean Coal Co. Ltd.

A similar installation at the company's Treharris colliery has been working most successfully for several years and a third plant is now under construction.

Bureau of Standards

G.E.C. Journal

IN THIS ISSUE.

ELECTRICAL PROGRESS AND DEVELOPMENT DURING 1936.

WITWATERSRAND GOLD MINING PRACTICE.

NOTES ON THE CALCULATION OF NETWORK SHORT CIRCUITS.

TELEVISION—FUNDAMENTAL PRINCIPLES.

SCIENCE AND ELECTRIC LIGHTING.

Vol. VIII., No. 1. *February, 1937*

THE GENERAL ELECTRIC CO. LTD
ENGLAND

G.E.C.

THE LARGEST BRITISH ELECTRICAL MANUFACTURING ORGANISATION IN THE EMPIRE

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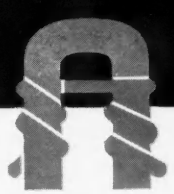
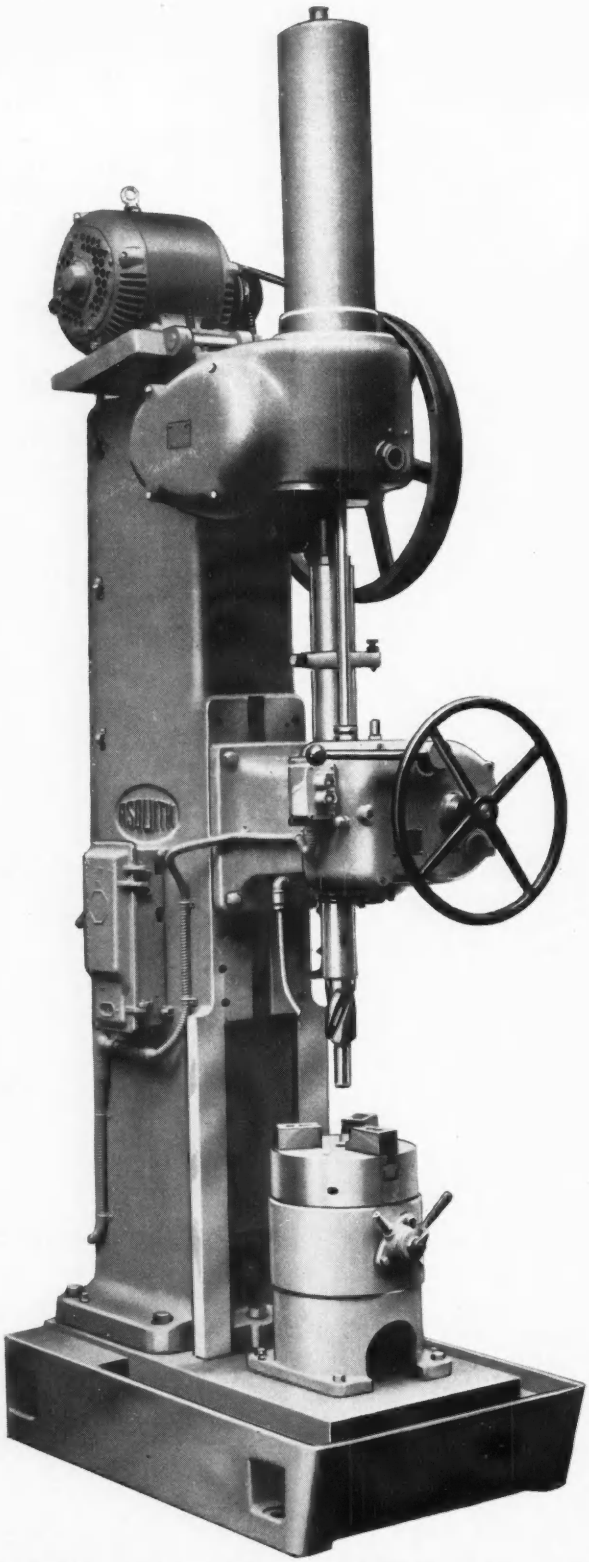


PIONEERS IN EVERY PHASE OF ELECTRICAL DEVELOPMENT



ASQUITH

THE NEW ASQUITH "U. F. D." PRODUCTION VERTICAL DRILLING MACHINE.

Illustration shows the type in the single spindle form, with Fixture and Component in position. Multiple spindle heads can be accommodated and driven to full efficiency. Can also be supplied in multi or gang form.

Features of the new "U.F.D." design include—

1. Massively proportioned column with closely ribbed base.
2. Multi V-rope drive — silent, efficient, shock-absorbing. (Machine is illustrated with guard removed.)
3. Instant application of spindle power traverse through drop feed worm.
4. Speed and feeds variable when required by the use of slip-on change gears.
5. Vertical adjustable Spindle Head at five different locations determined by height of component.

Detailed specification on request.

WILLIAM ASQUITH LTD., Well Road Works, HALIFAX

Sole Representatives for the Midlands and Southern Counties of England :

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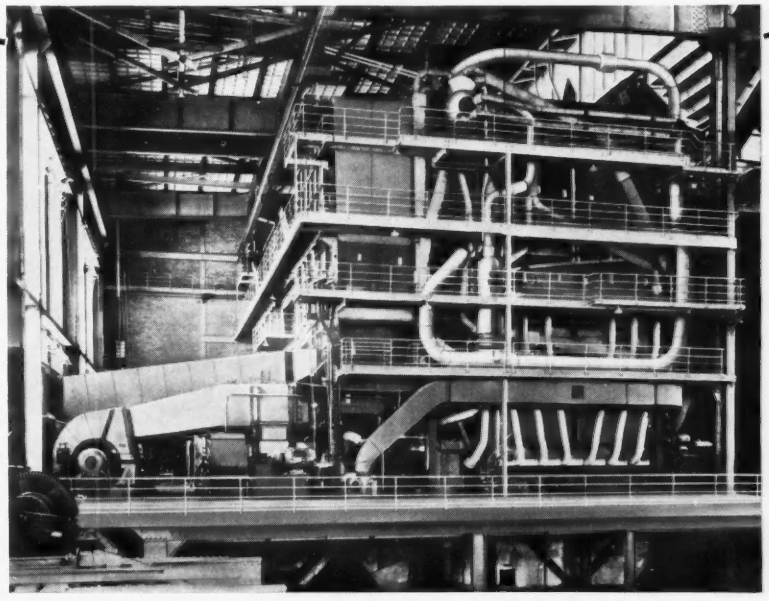
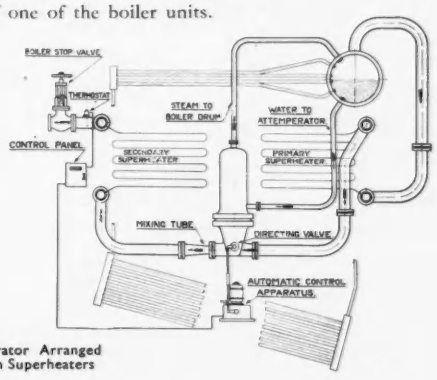
NIJMEGEN
POWER STATION



THE GELDERLAND ELECTRIC POWER CO., HOLLAND

4 Babcock & Wilcox Water Tube Boilers have recently been put into commission, each for a maximum continuous rating of 226,400 lbs. of steam per hour at 565 lbs./sq. inch and 842°F. The boiler units comprise B. & W. Style 28 Stokers—Twin 27 ft. by 24 ft., Bailey Furnaces, Babcock Class One Fusion Welded Boiler Drums, B. & W. Flash Welded Economisers, 2 B. & W. superheaters per boiler in series with an attemperator.

The arrangement of the superheaters and the attemperator results in very close regulation of final steam temperature. The attemperator consists of a number of U tubes through which part of the steam is passed; these U tubes are immersed in water taken from the boiler drum and the steam generated is taken back to the drum. The proportion of the steam passing through the U tubes is governed by a directing valve, movement of which is controlled by a thermostat placed in the steam pipe immediately in front of the boiler stop valve. The effect of the arrangement is that any increase in temperature of the outlet steam beyond a pre-determined figure causes the directing valve to close against the main steam flow and to pass a greater proportion of the steam through the cooling tubes; a fall in temperature has the opposite effect. The arrangement is shown clearly diagrammatically below, whilst the attemperator and its connecting piping can be seen in the illustration of the side view of one of the boiler units.



Attemperator Arranged between Superheaters

Our reprint No. 1213, from a technical paper article, describes this installation in detail and will be sent on request.

33 BAILEY FURNACES ARE INSTALLED IN, OR ARE ON ORDER FOR HOLLAND.

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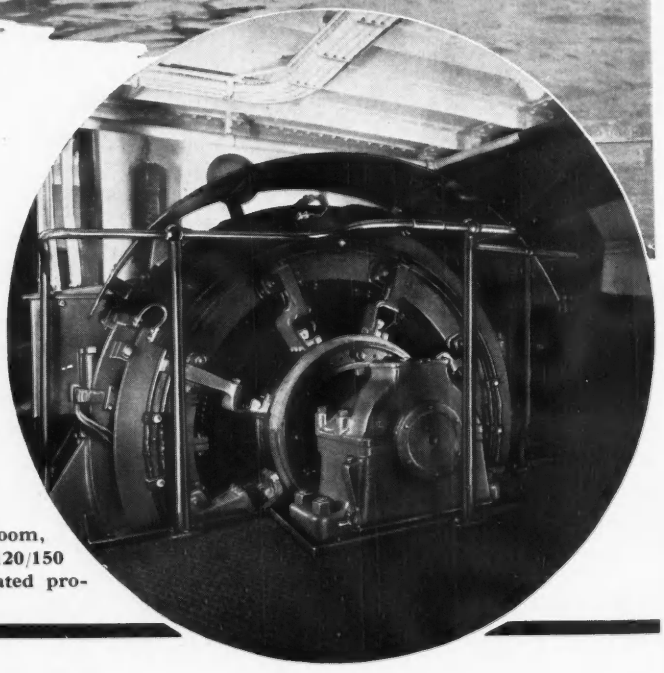
ELECTRIC PROPULSION EQUIPMENT *for* TUGS

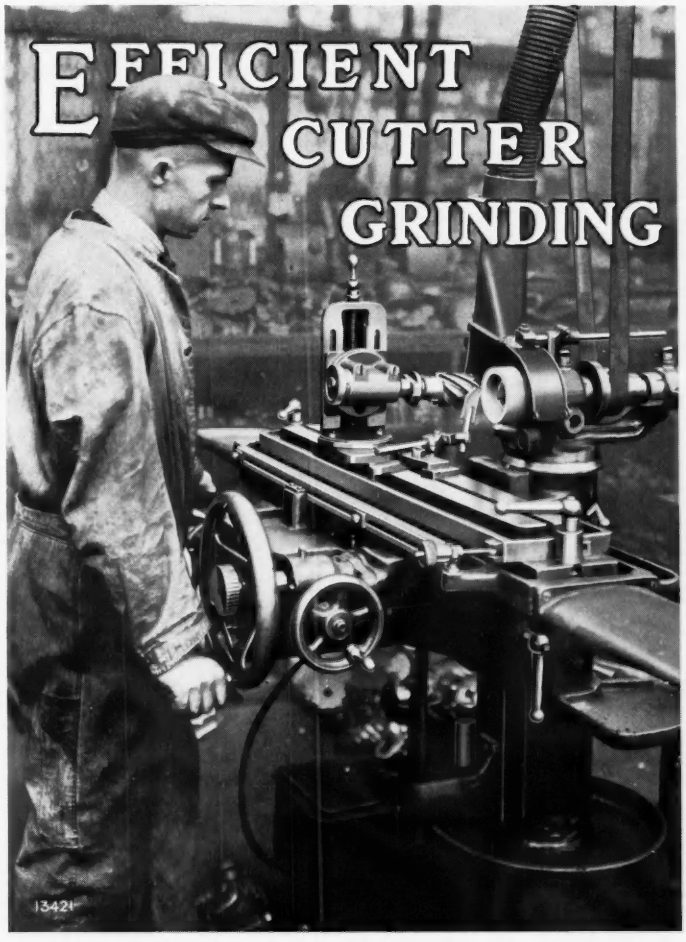
DIESEL-ELECTRIC TUG
"SIR MONTAGU"

The Diesel-electric tug *Sir Montagu*, equipped with G.E.C. electric propulsion machinery and built by Smith's Dock Co. Ltd., Middlesbrough, is now in service on the Thames. This small river tug completed the open sea journey from the Tees to the Thames, a distance of 302 sea miles, in 32 hours. Very heavy weather was encountered throughout the voyage.



After end of engine room, showing 350 s.h.p. 120/150 r.p.m. forced ventilated propulsion motor.

HERBERT



THE Herbert No. 4 Patent Universal Cutter and Tool Grinder will deal with all kinds of cutters and tools quickly and efficiently. The most delicate cutting edge can be ground without drawing the temper owing to the efficient wet grinding system. The combined quick and slow movements of the table and saddle enable a wide range of work to be ground without special attachments. Equipment can be supplied for grinding cutters and reamers, machine-relieved cutters, large inserted tooth cutters and large saws, hobs with spiral flutes; for surface grinding, internal and external circular grinding, index grinding.

Capacity: 10″ (or 12″ with raising blocks) × 27″

IMMEDIATE DELIVERY

We also make a Motor-driven Machine, capacity. 10″ × 21½″

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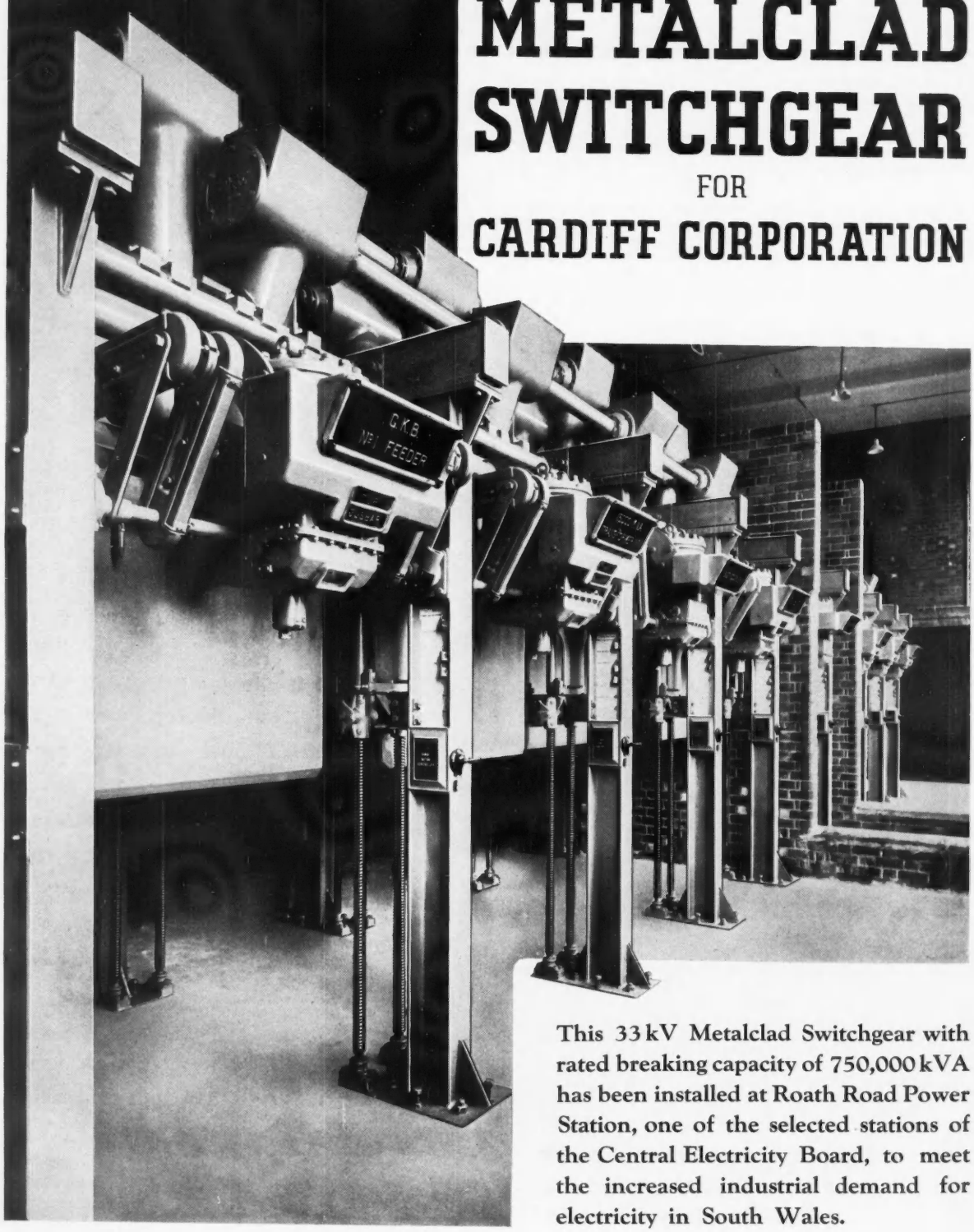
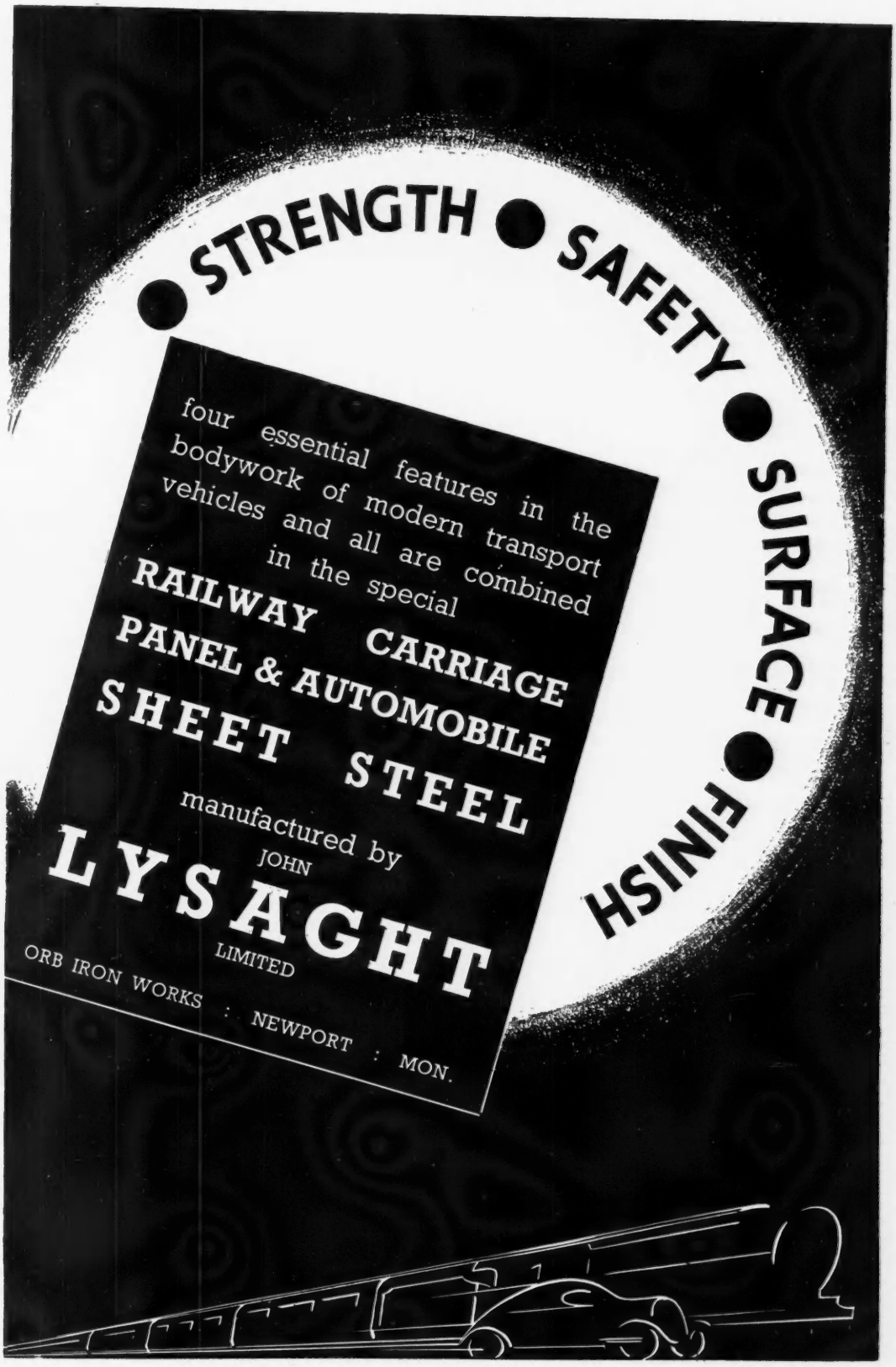
METALCLAD SWITCHGEAR

FOR

CARDIFF CORPORATION



This 33 kV Metalclad Switchgear with rated breaking capacity of 750,000 kVA has been installed at Roath Road Power Station, one of the selected stations of the Central Electricity Board, to meet the increased industrial demand for electricity in South Wales.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PRINTED IN ENGLAND.

G.E.C. Journal

Bureau of Standards
JUN 3 1937

IN THIS ISSUE

LUMINESCENCE AND ITS APPLICATIONS

THE PANGANI HYDRO-ELECTRIC SCHEME

THE APPRAISEMENT OF LOUDSPEAKERS PART II.

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UNIFORMITY AS THE GAUGE OF QUALITY

INDUSTRIAL FLOODLIGHTING

TELEVISION RECEIVERS PART I.

Vol. VIII., No. 2. *May, 1937*

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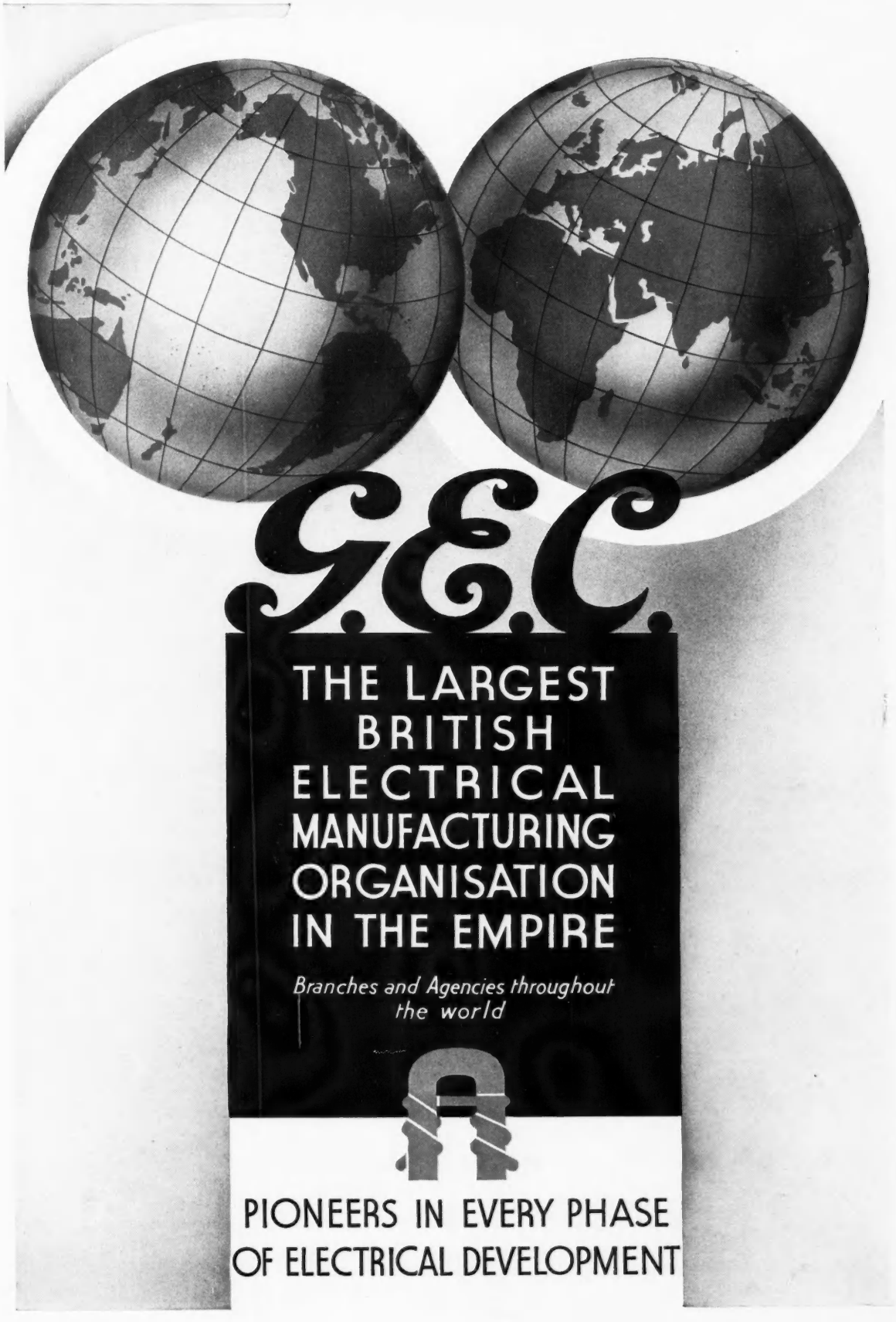
ENGLAND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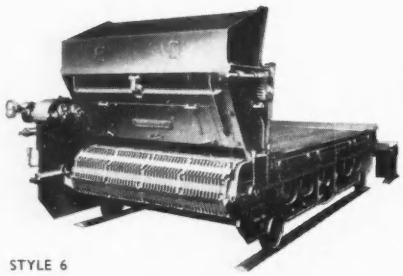
STOKERS

THE Babcock & Wilcox Stoker is the outcome of the Company's experience in the design and manufacture of stokers from 1883 to the present day, and the features of the present stokers were developed with the sole idea of producing a sound product based on the results obtained in many thousands of installations dealing with all classes of fuel.

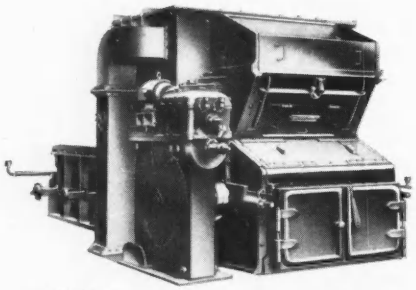
The Company manufactures three types of stokers, viz. the Styles 6 and 31 Chain Grate Stokers and the Style 28 Travelling Grate Stoker. All types are suitable for burning any free-burning bituminous coal, and the Styles 31 and 28 Stokers are, in addition, particularly applicable for anthracite, coke breeze, lignite, low volatile fuels, and low grade fuels generally.

The use of each style of stoker is governed by the type of fuel to be burned, the load to be carried and the range of load to be covered, which factors are too broad to enable a single design of stoker to be applied universally.

The bottom illustrations show a Style 28 Stoker 33′ 0″ wide, which is one of 22 such Stokers supplied to a single Power Station. All the illustrations are taken from our recent publication, a copy of which will be sent on request.

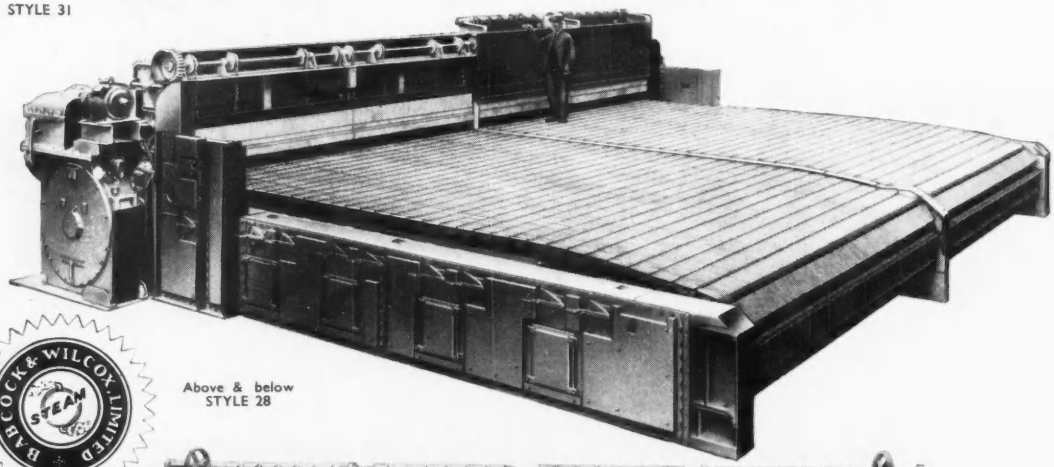


STYLE 6



STYLE 31

CATALOGUE No. 1208—STOKERS



Above & below
STYLE 28

BABCOCK & WILCOX LTD.

BABCOCK HOUSE, 34 FARRINGDON STREET, LONDON, E.C.4.

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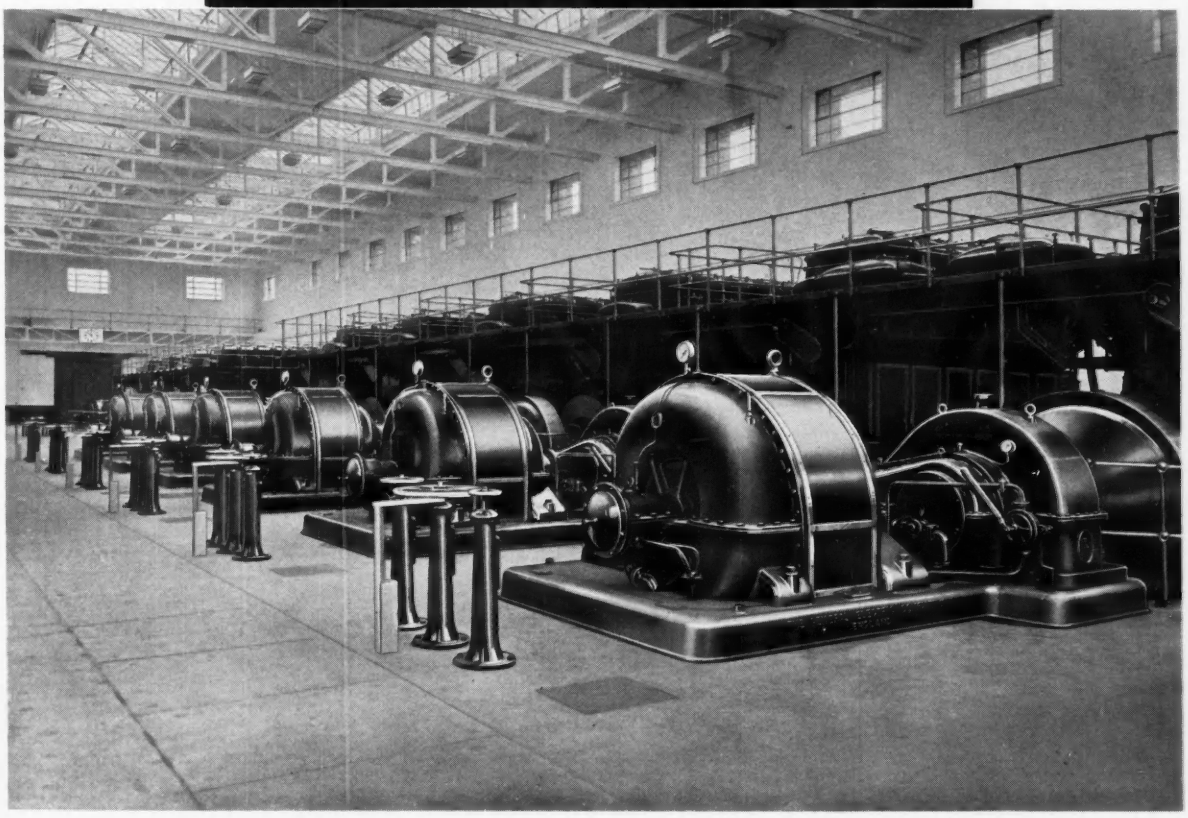
MIDDLESEX COUNTY COUNCIL



Six 650 h.p. Fraser & Chalmers turbo-blowers, each running at 3,030 r.p.m. and delivering 15,000 cu. ft. of air per min. against a pressure of 5/9 lbs. per sq. in. These turbo-blowers are installed at Mogden to provide the compressed air for the sludge activation process used in the Middlesex County Council sewage purification scheme.

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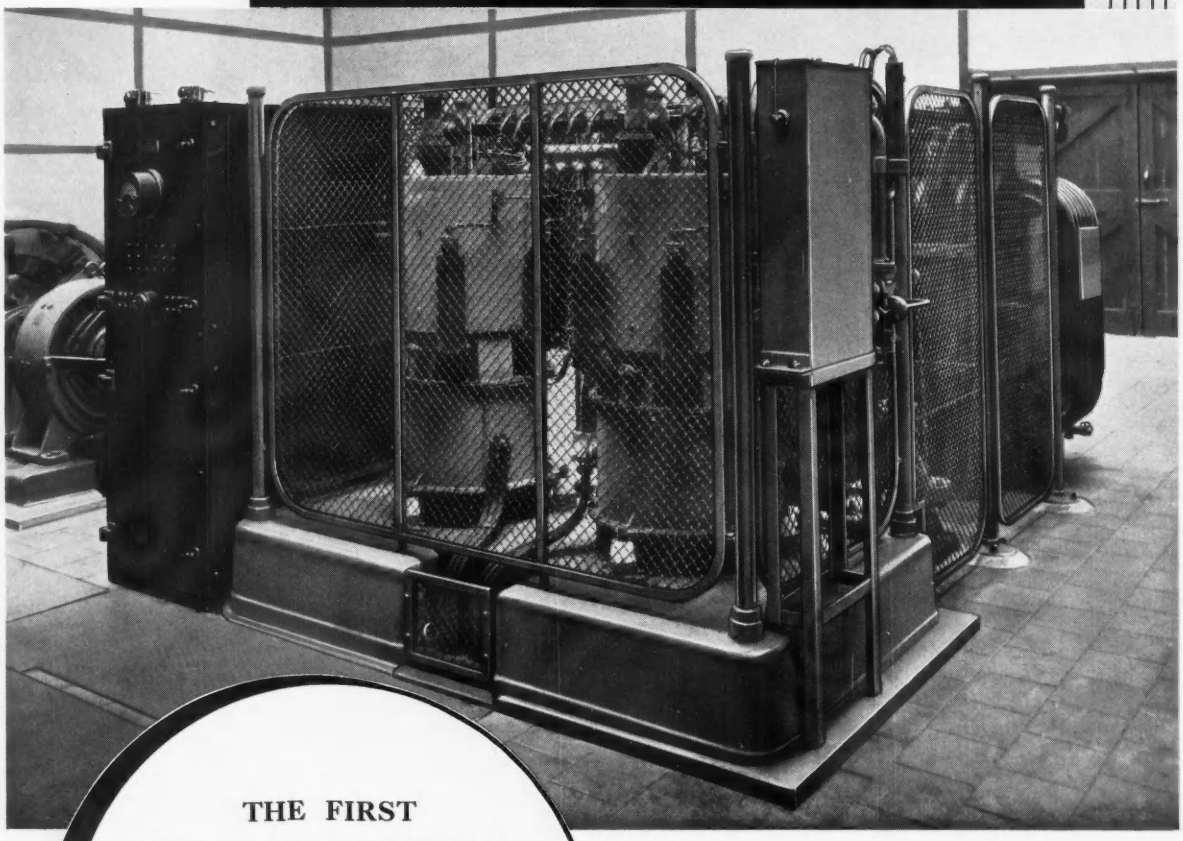

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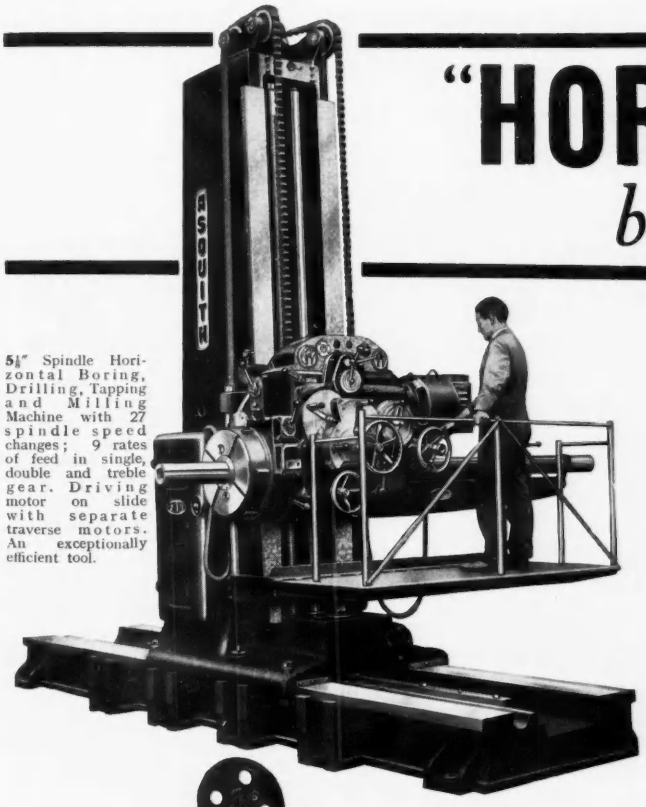
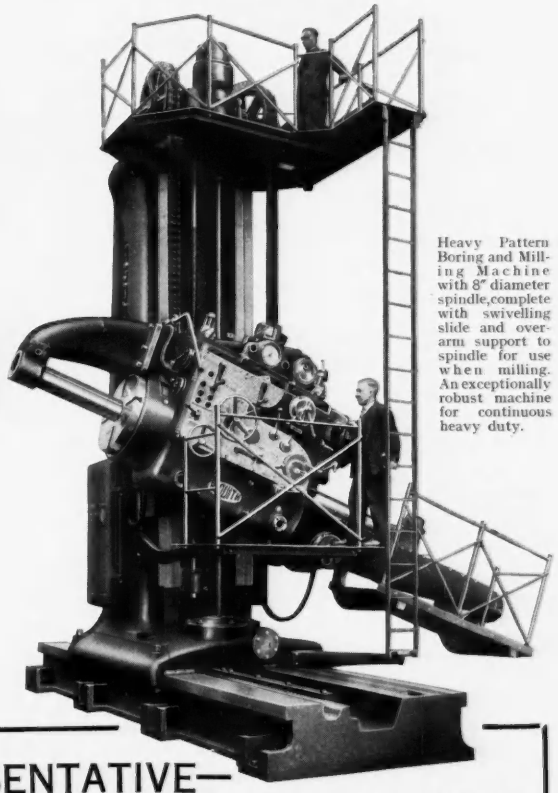
"HORIZONTALS"

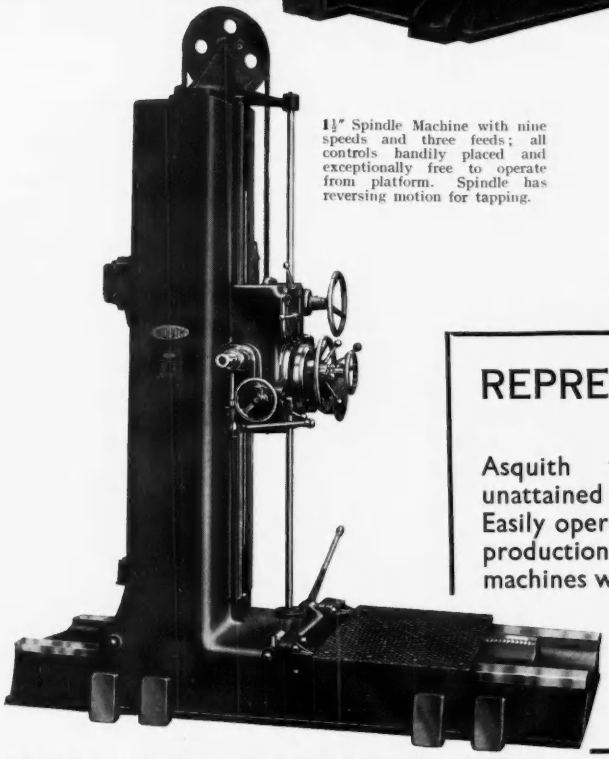
by ASQUITH



5½" Spindle Horizontal Boring, Drilling, Tapping and Milling Machine with 27 spindle speed changes; 9 rates of feed in single, double and treble gear. Driving motor on slide with separate traverse motors. An exceptionally efficient tool.



Heavy Pattern Boring and Milling Machine with 8" diameter spindle, complete with swivelling slide and overarm support to spindle for use when milling. An exceptionally robust machine for continuous heavy duty.



1½" Spindle Machine with nine speeds and three feeds; all controls handily placed and exceptionally free to operate from platform. Spindle has reversing motion for tapping.

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Asquith "Horizontals" have established hitherto unattained standards in soundness of design and efficiency, Easily operable and with ample reserve of power, highest production rates are always achieved. Range includes machines with spindles from 1½" diameter upwards. Milling feeds available on the larger scales.

Complete catalogue shortly available. Full details meantime of any individual type upon request.

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THE LARGEST ELECTRIC TRAVELLING BAKING OVEN IN GREAT BRITAIN

This electric travelling oven is 41 ft. in length and 8 ft. 6 ins. wide, and is capable of baking 850 lbs. of cake an hour. It forms part of the equipment at Oliver & Gurden's new premises at Oxford, for which the whole of the electric baking equipment was designed and manufactured by the G.E.C.

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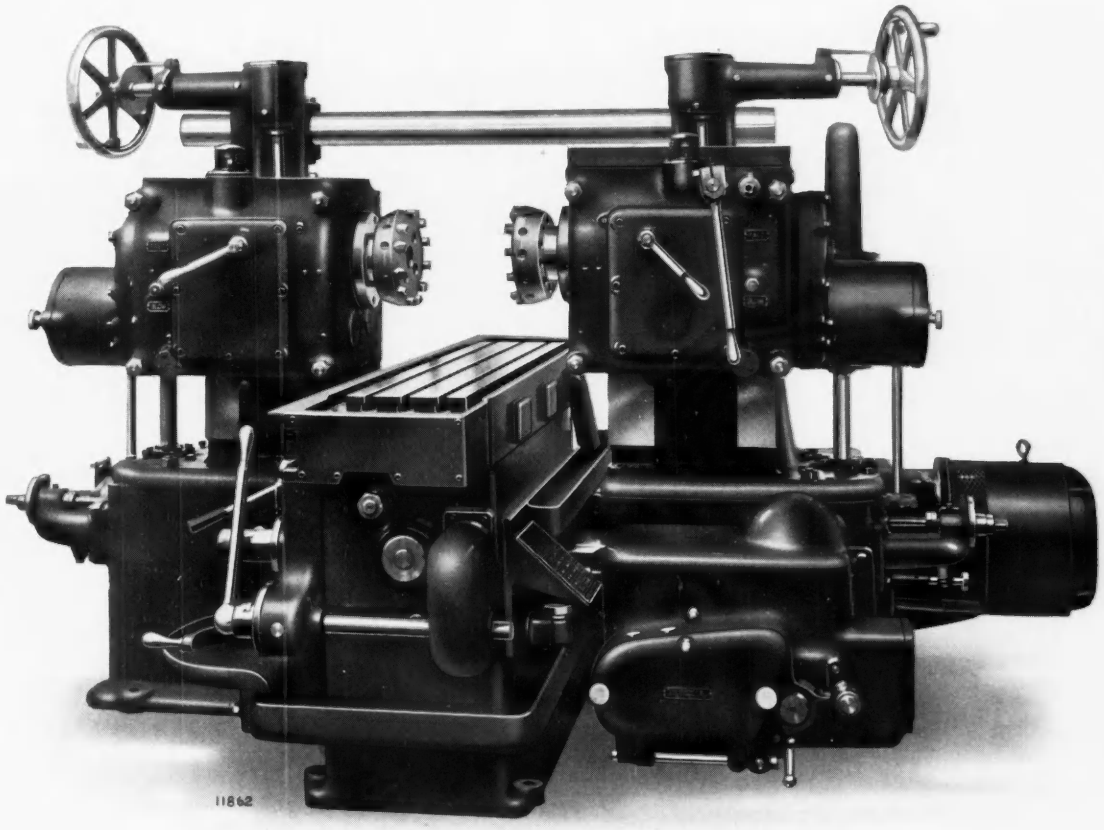

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A powerful, heavy-duty machine for milling quantities of parts made of steel, cast-iron or non-ferrous metals

Wide speed and feed ranges enable large or small cutters to be run at appropriate speeds.

Complete automatic cycle of table movements.

Roller-bearing spindle, ball or roller bearings to all shafts, chrome-nickel steel gears, automatic lubrication.

MADE WITH SINGLE OR DUPLEX COLUMNS

Automatic longitudinal feed 36″
Max. distance between spindles 22½″.
Max. distance from spindle to table 12″.
Sixteen spindle speeds 20 to 761 r.p.m.
Eighteen feeds 1″ to 41¼″ per min.

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G.E.C. Journal

Bureau of Standards
AUG 21 1937

IN THIS ISSUE.

AN EXPERIMENTAL MULTI-NOTCH CONTROL EQUIPMENT FOR LONDON TRANSPORT TUBE RAILWAYS.

MODERN RECEIVING VALVES: DESIGN AND MANUFACTURE PART I.

THE REMOTE INDICATION OF METER READINGS.

STATISTICAL TECHNIQUE AS A TOOL IN INDUSTRY.

COLOUR FLOODLIGHTING FOR THE CORONATION CELEBRATIONS.

RECENT EXTENSIONS TO THE GENERATING PLANT AND SWITCH-GEAR AT HAMS HALL POWER STATION.

TELEVISION RECEIVERS—PART II.

THE PRODUCTION OF AIR MOVEMENT BY ELECTRIC FANS.

A MODERN NEWSPAPER HOUSE IN AUSTRALIA.

Vol. VIII., No. 3. *August, 1937.*

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The G.E.C. has developed Bright annealing to a degree that enables the product treated to be delivered literally from furnace to customer.

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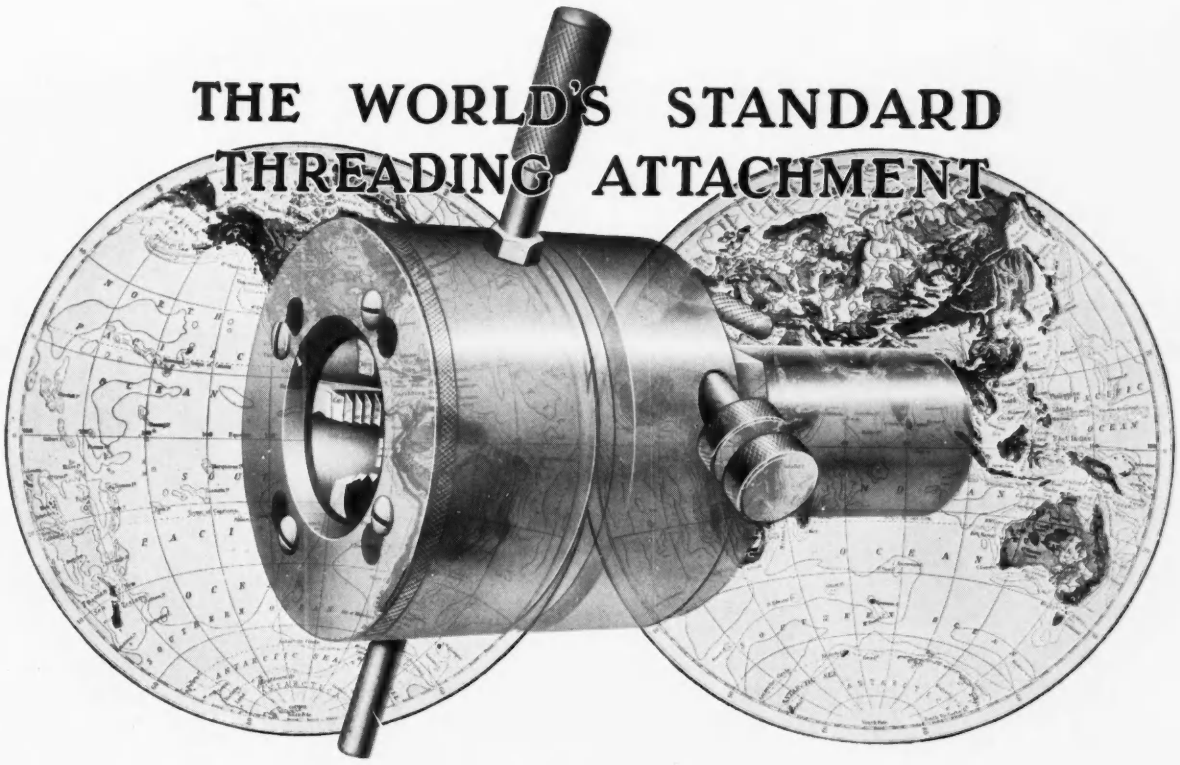

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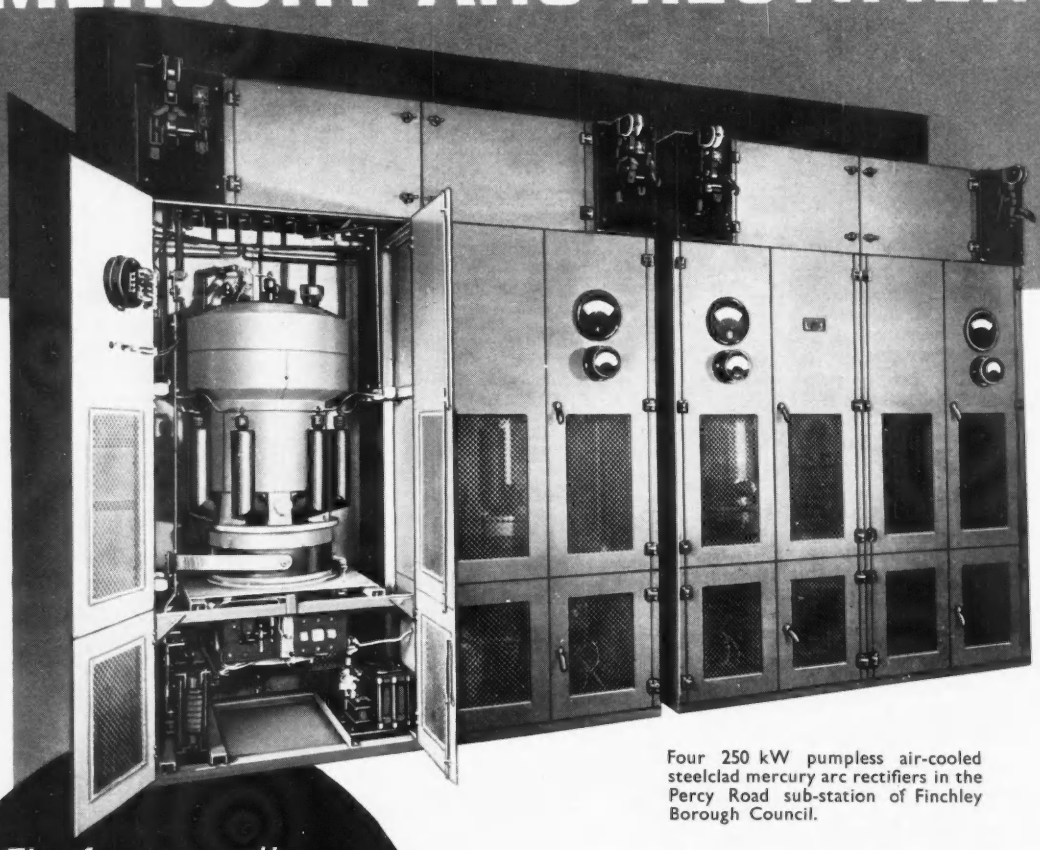

Four 250 kW pumpless air-cooled steelclad mercury arc rectifiers in the Percy Road sub-station of Finchley Borough Council.

The first installation in the world of Pumpless Air-Cooled Steelclad Mercury Arc Rectifiers for **MUNICIPAL SERVICE**

Previous to the completion of this installation the G.E.C. had already installed the first air-cooled steelclad rectifiers in the world for traction and industrial service respectively.

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COAL HANDLING PLANT

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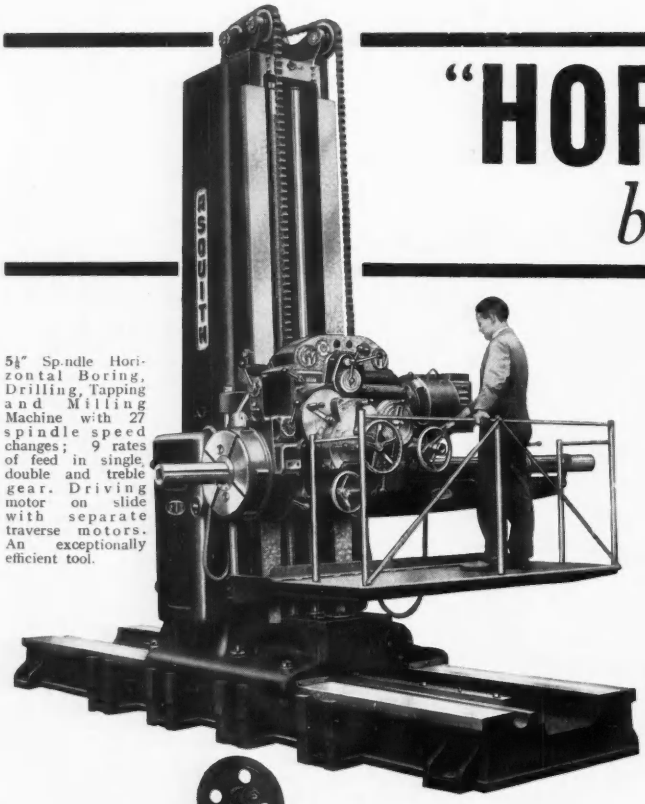
A coal handling, storing and shipping plant with a capacity of 400 tons an hour has recently been supplied and erected by Fraser & Chalmers Engineering Works for the Lunghai Railway of the National Government of China.

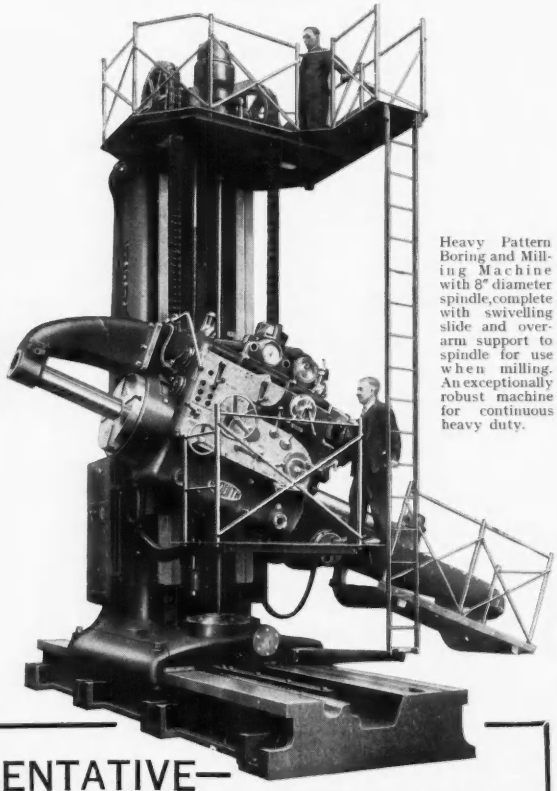
This view shows the storage ground and part of the plant. A travelling throw-off carriage operates along the belt conveyor in this bridge, delivering coal to the storage ground, which is 1,640 feet long and is capable of holding 160,000 tons of coal.

"HORIZONTALS"

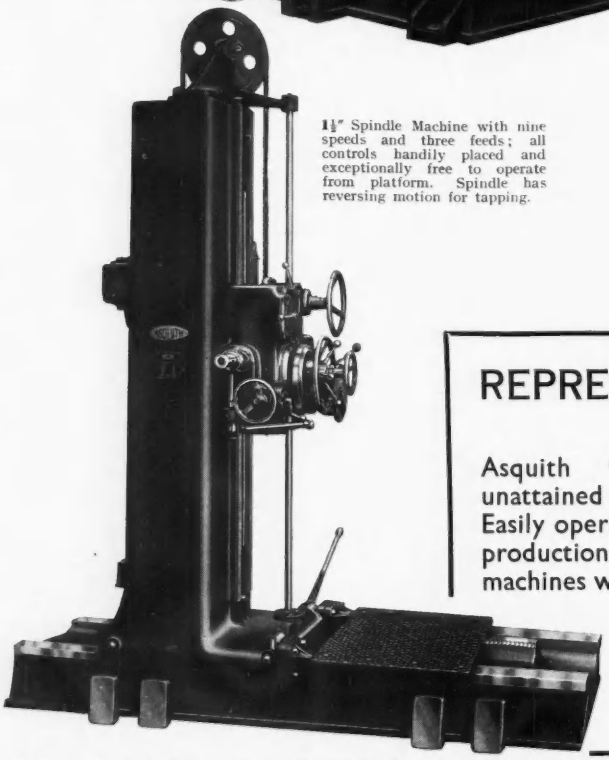
by ASQUITH



5½" Spindle Horizontal Boring, Drilling, Tapping and Milling Machine with 27 spindle speed changes; 9 rates of feed in single, double and treble gear. Driving motor on slide with separate traverse motors. An exceptionally efficient tool.



Heavy Pattern Boring and Milling Machine with 8" diameter spindle, complete with swivelling slide and overarm support to spindle for use when milling. An exceptionally robust machine for continuous heavy duty.



1¾" Spindle Machine with nine speeds and three feeds; all controls handily placed and exceptionally free to operate from platform. Spindle has reversing motion for tapping.

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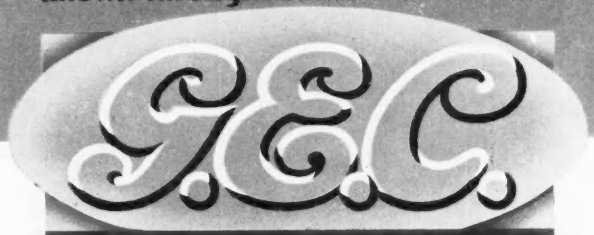

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EARLS COURT SWIMMING POOL.

SECONDARY-ELECTRON EMISSION FROM COMPLEX SURFACES.

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AUTOMATIC POWER STATION EQUIPMENT IN SOUTH AFRICA.

AN ELECTRO-ACOUSTIC TESTER FOR LOUDSPEAKERS.

THE ELECTRICAL CONTROL OF PAPER MAKING MACHINERY.

TECHNICAL LITERATURE.

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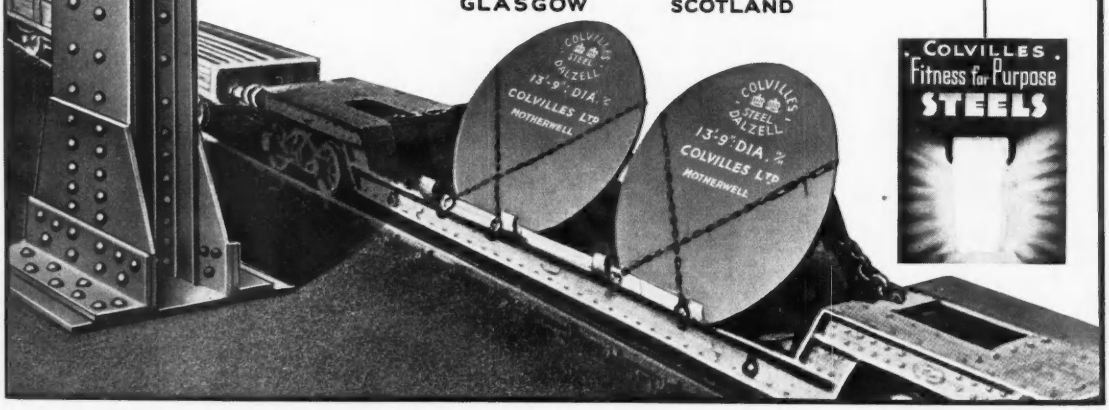

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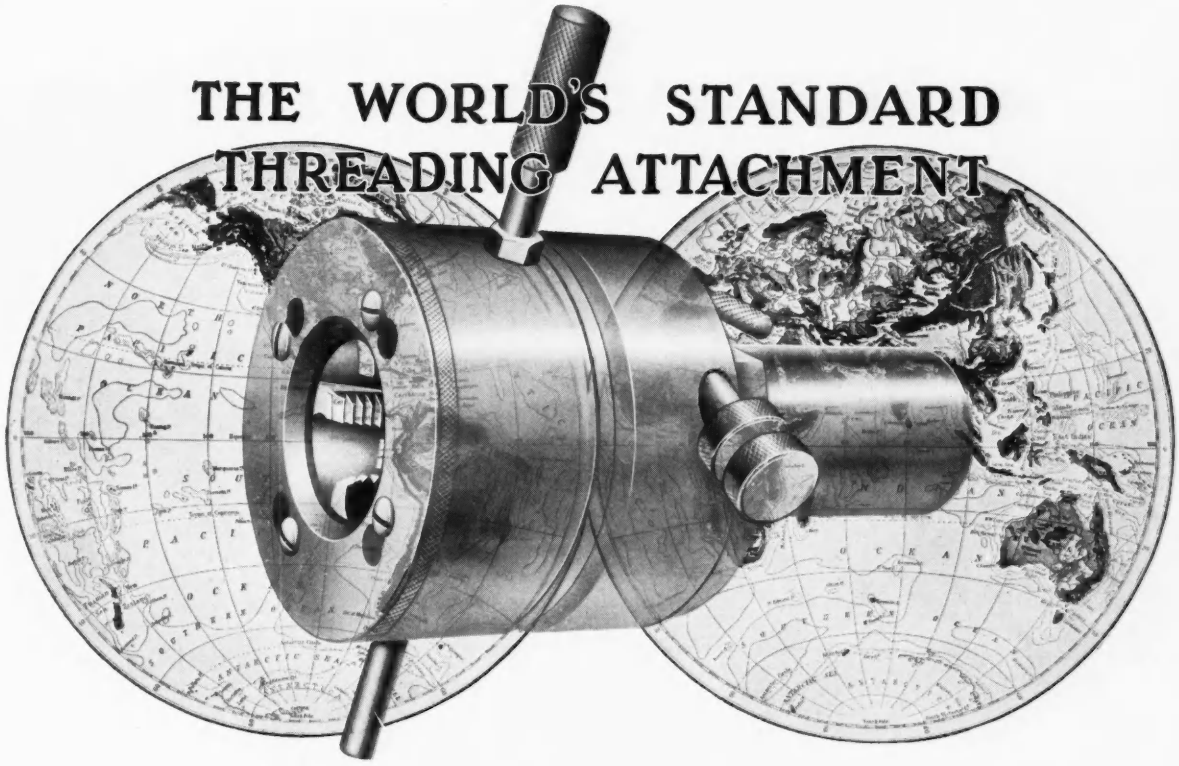

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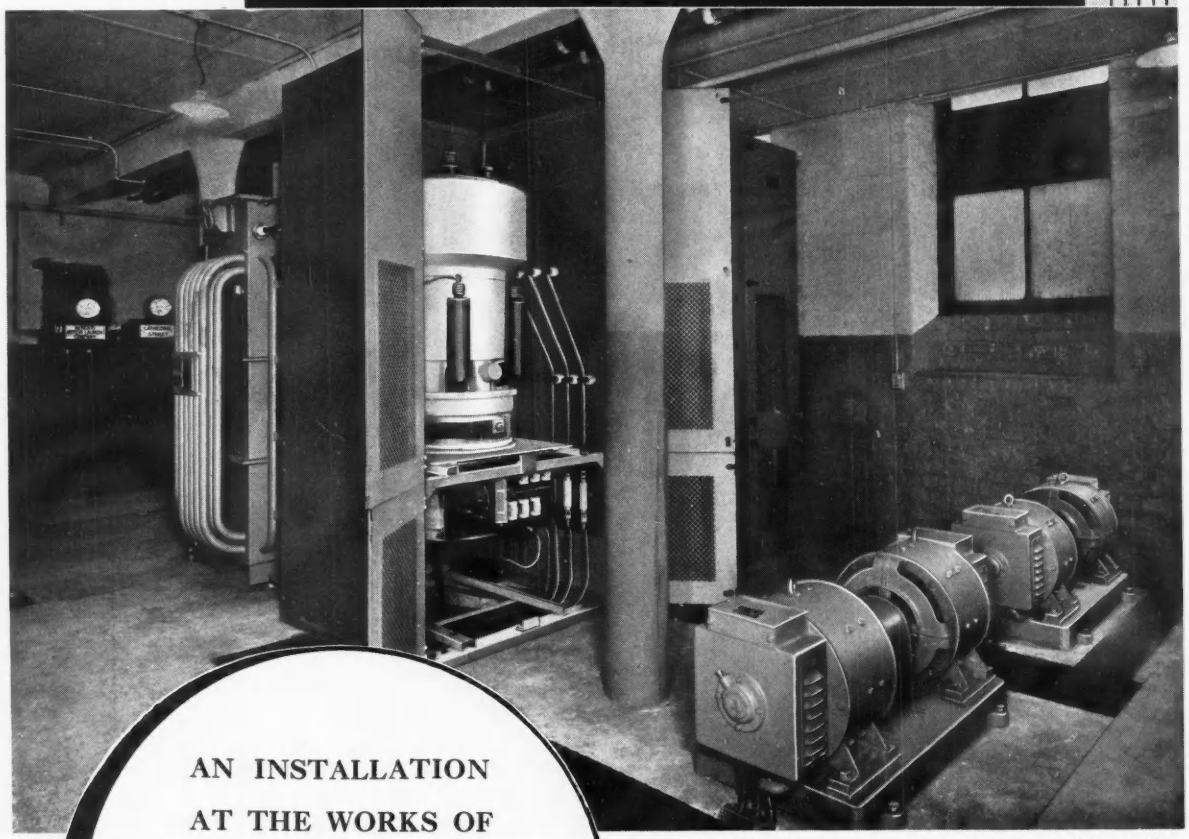

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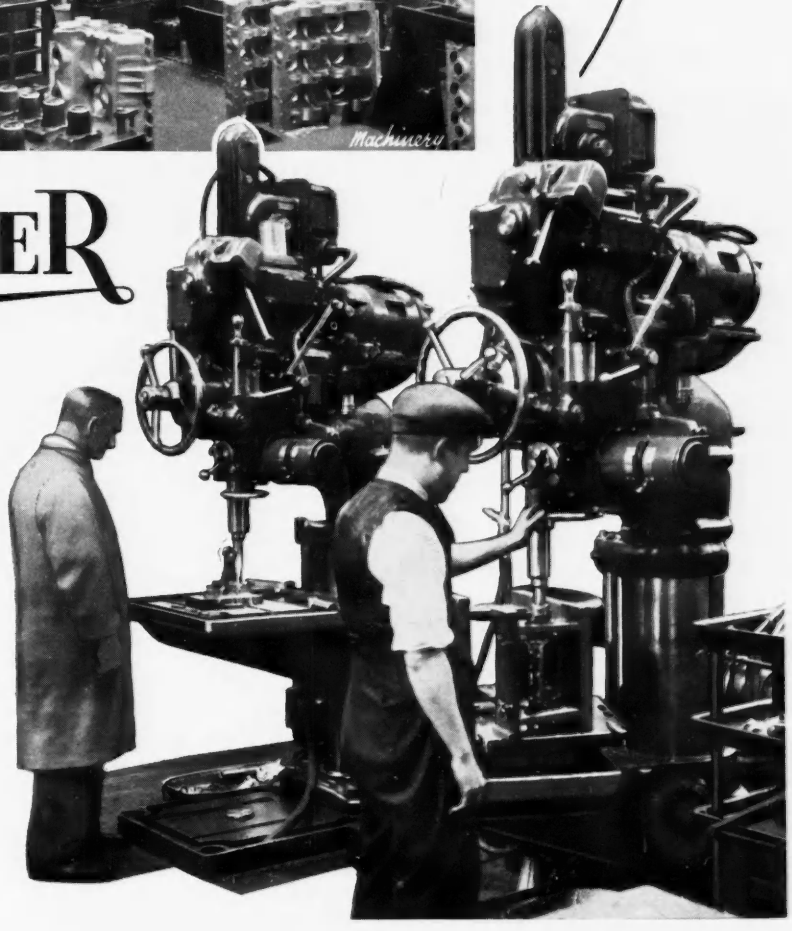

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